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The list of conference participants appears in Design for the Nuclear Age.

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Milton C. Coon Jr.

MILTON C. COON, JR.
Executive Vice President

Contents

Needs for Fasteners to Wood and Wood Products

By Grant T. Edmonds, Johns-Manville Sales Corporation

Abstract: Major problems in the fastener industry are the need for more thorough field testing of fasteners and for published information on special types of nails and fasteners. The solution to these problems depends on close cooperation between building materials manufacturers and the fastener industry and on increased research and development. Specific needs for more study are cited in the areas of staple guns, roofing nails that will not "back out," applying shingles to non-standard types of roof decking, hand versus power stapling, methods of fastening to plywood decks in built-up roofing, and application of sheet materials to sidewalls over a nailable base.

MORE THAN 2000 YEARS AGO nails were used by the Ancient Romans to ward off evil spirits and to cure illness. They believed that by simply driving a nail into a tree, wall, or other surface they would leave their ailments behind, firmly nailed down, never to bother them again. We in the building industry have not really changed very much since then. We now nail our products to a by-product of a tree, used as a wall or other surface, but there the similarity ends because our firmly nailed-down product, rather than being left behind, sometimes continues to haunt us through the years. This allegoric tale, noted in a recent issue of one of our trade journals, is not meant to be an indictment of the fastener industry, but rather to lead into the subject at hand.

In its early years our company sold asbestos in the form of shingles, roofing, and pipe insulation. Today, this simple list has mushroomed to a staggering variety of building products in many forms, composed of asbestos, cement, metal, wood, plastics, glass, and foam. Likewise, the base or deck over which we formerly applied our building product finishes was generally 1 inch x 8 inch wood sheathing. Keeping pace with the multiplicity of covering materials, substrate materials have expanded to include numerous types of plywood, particle boards, fiber boards, and wood fiber combined with binders such as gypsum, plastic foam, and cement.

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In the old days, we fastened practically all wood and roof-covering materials with ordinary nails. Today, because of the variation in density, and other physical characteristics of modern sheathing materials which have a direct bearing on the holding power of the fasteners, many new types of mechanical fasteners have been developed. There are on the market today over 400 different kinds of mechanical devices for fastening various types of materials to so-called nailable wood base products.

PROBLEM OF VARIETY OF FASTENERS

One of the major problems building materials manufacturers encounter today is the tremendous variety of special nails and fasteners available, many of which are sold with somewhat extravagant claims. In many cases the manufacturer of the nail or special fastener has not thoroughly pretested his product under actual field conditions. Consequently, the manufacturers of building materials often find themselves involved in a situation where their products have failed due to the unsatisfactory performance of the fastener.

To illustrate this point we recently passed on a request to a nail manufacturer to provide a nail for use in securing aluminum siding to a nailable base sheathing. These units were to be fastened at the head through a relatively thin flange, thus a long nail was not necessary to achieve proper penetration of the substrate. In the interest of economy, the fastener manufacturer submitted a nail 1/2 inch long. In theory this was ideal since, with twice as many nails to the pound, the cost of fasteners was cut in half. But what about the mechanic who has a thumb 1'' wide? How could he hold onto one of these dainty nails, let alone drive it without bashing his thumb?

In this instance the human element had been overlooked. To illustrate the importance of the human element, when seeking material for this paper we were advised by the president of a large roofing and siding manufacturing company that in certain geographical locations they must furnish a siding shingle face nail 1/4 inch longer than usual, because mechanics wear gloves and require the extra length so they can hold the nail.

We had an experience earlier this year wherein an architect had specified the application of our asphalt shingles over a nailable wood composition deck. Since we had not had satisfactory experience in applying our shingles over this particular manufacturer's deck, we asked the company for its recommended fastener specification. They gave us the name of a special expanding fastener. In checking further with the fastener company, we found there was no commercially available accessory of this type. Thus we found ourselves being pressured by the local school board to ship our shingles, yet we were unable to develop a proper specification for applying them over a deck specified by the school architect. It is interesting, though disturbing, to report that after everyone had become thoroughly annoyed, a plywood deck was installed over the "nailable" product and our shingles were then fastened to the plywood by conventional means.

Since then, we have seen a prototype fastener for this very application which, although not yet available, should solve the problem of fastening asphalt shingles to these decks. However, the deck manufacturer was not the initiator of this development; it was left up to the fastener manufacturer. A point we wish to stress is that it would help everyone all along the line if manufacturers of nailable base products would thoroughly test out their materials, and publish definite information on any special types of nails or mechanical fasteners required to develop proper holding power and retain water tightness. This responsibility should not be put upon the covering material. It is also important not to specify special fasteners if they are not available on short notice.

In another instance, we had a request to provide information on the proper type of nail or fastener to secure an asbestos-cement shingle to a particular nailable deck. We recommended a special type of roofing nail. When our customer called the nail manufacturer, he was told these nails were not a stock item (although we had periodically confirmed this with the supplier) and that there would be a delay of three weeks for manufacture, and a minimum "five-keg order." Here again, we must all be more realistic. If the nailable deck manufacturer expects to sell a product over which regular roofing materials are to be applied, then either the deck manufacturer must supply the proper nails, or the nail manufacturer must make them available in reasonably small quantities. It is unrealistic to expect a roofing manufacturer to stock the great variety of nails and fasteners required to secure his products to each of the many types of nailable base materials on the market today.

At this point, it might be well to report on a situation where close cooperation between the fastener manufacturer and the building material manufacturer resulted in a rapid and successful solution to a problem. Several years ago there was introduced a 1/2 inch nail base fiberboard sheathing with physical characteristics that made it possible to secure siding units directly without the use of wood nailing strips, metal channel mouldings, or expanding-type fasteners. The product had a tremendous sales potential, since it was something new and revolutionary in the building products field, but it needed a nail that would do all that was required of it. We experimented with many standard fasteners, but not one included all the necessary features. We explained our problem to the fastener producers and, as a result of close cooperation between them and us as sheathing manufacturers, the optimum nail was successfully developed and now has industry-wide acceptance for use with nail base fiberboard sheathing. This example is cited to emphasize the responsibility of the substrate manufacturer to provide the applicator of the finishing materials with a complete specification. It is true that some manufacturers produce both the nail base fiberboard sheathing and the siding units. Therefore, they have an obligation to furnish, or at least recommend a fastening system, which all too often is not done.

NEED FOR RESEARCH

To pinpoint some specific areas in which we feel that additional research and development of nail and fastener products are needed, several cases are cited below.

For many years asphalt roofing shingles have been applied with ordinary galvanized needlepoint roofing nails, but recently some progress has been made in the stapling of this type of product to wood decks. In such applications, considerable variation occurs in tear resistance to wind uplift of asphalt shingles, depending on the direction of the staple crown with respect to the shingle itself. If the staple is driven so that its crown is parallel to the butt line of the shingle which is, of course, parallel to the eave and ridge, a certain tear-off resistance is developed. However, using the same staple applied so that the crown points toward the ridge of the roof, or at a 90° angle to the shingle butt, a much greater tear resistance is developed. And, staples driven at a 45° angle develop a resistance about halfway between the other two.

The normal way to drive a staple, from the standpoint of the mechanic working on the job, would place the staples more or less parallel to the eave, which is the weakest position as far as tear resistance is concerned. To achieve maximum resistance, the staples should be applied vertically, which makes it almost impossible for the mechanic to hold the stapling tool comfortably. Another point involved is whether the staples are hand-driven or power-driven. If a hand-driven, hammer-type tool is used, then the angle of the staple in the shingle will depend on the arc the mechanic develops as he reaches to the left to fasten the shingles on his left, and then swings in an arc to complete the fastening of the units on his right. Obviously, the angle of the staple will be considerably different as the mechanic proceeds through each fastening cycle. Since it is not practical to watch the mechanic as he drives each staple, we need some type of staple gun which permits a mechanic to fasten the shingles conveniently, and still have the staples all driven in approximately the same relation to each other. If using the tool forces the mechanic to stand in an awkward or overbalanced position, he will not use it.

Another problem that has plagued roofing manufacturers for a long time is the tendency for ordinary roofing nails to "back out" of a wood deck after being exposed for several summer seasons. It is an extremely slow but continuous process which, after it progresses far enough, can cause leaking as well as an unsightly appearance. We realize that threaded shank nails can be substituted, but they are more expensive and, because of the highly competitive nature of this particular trade, it has not been possible to get roofing contractors to use anything but standard roofing nails for this purpose. There is undoubtedly a need for additional educational effort on the part of roofing manufacturers to emphasize the fact that the additional cost of a threaded nail would more than offset possible roof repairs. It would help immeasurably if a roofing nail were made available which was not any more expensive than the standard product, and which would not back out when used in an exposed position on a roof.

For many of the nailable-type roof decks on the market today, the nail specified is of a special, expandable nature. In order to provide the expanding feature, the head of the nail is made considerably thicker than an ordinary galvanized roofing nail. This develops a problem in the case of asbestos-cement roofing shingles, because the two overlapping shingles are held apart by the thickness of the nailhead. This may result in leakage in a driving rain, and also in breakage in areas around dormers where one must step on the shingles to remove a storm window, or during a painting operation. The same problem of using expandable fasteners exists in connection with asphalt roofing shingles. These, being considerably softer than the asbestos-cement type, do not offer sufficient back-pressure to fully expand the fastener, particularly in hot summer weather when the roofing is softened by the heat of the sun.

Tin roofer's caps or discs have been used in some applications, to act as an anvil against which the nailhead can compress. However, water leakage has usually resulted, as the cap prevents the fastener head from sealing in the relatively soft asphalt. In normal application to wood decks, we do not usually encounter any difficulty when a standard galvanized roofing nail is used, since its large flat head seats itself firmly and offers practically no thickness to separate the overlapping shingles.

With the increase in the number of architects specifying special types of nailable roof decks, and also decorative roofs of either asphalt or asbestos-cement shingles, we automatically encounter the problem of fastening into these non-standard deck surfaces. The required fastener must not be the cause of leakage or breakage, which has too often been the case in the past. It may seem trite to refer to the old adage "for want of a nail the battle was lost," but this is a very real battle between the deck and roofing manufacturers which will continue until the right fastener is made available at a price that will encourage its use.

TRENDS AND NEW PROBLEMS

Changes and trends in building design often present new problems. One we are encountering in the roofing business is the trend toward open soffits and unfinished ceilings of plywood sheathing in carports and porches. In most cases this is done in the interest of economy, or to satisfy the design of certain types of architecture. Under such conditions, it is obvious that to fasten roofing shingles with standard roofing nails will result in the exposed underside of the deck being conspicuously marred by the nail points projecting through the plywood. Not only is this unsightly but, due to the spalling of the plywood, some of the effective holding power of the shingle nail in the lower laminated ply is lost.

This problem was studied by the Sales Engineering Committee of the Asphalt Roofing Industry Bureau, and an industry specification was developed through the cooperation of the various members. A minimum of 1/2 inch exterior grade plywood was specified with barbed roofing nails to be of such length that they did not penetrate through the underside. Remembering the human element already referred to, obviously whatever nail was specified must be of such length that a mechanic could at least hold it, and the nail should be one readily available. Taking into account the 1/2 inch deck thickness and the multiple layers of asphalt shingles, we found that 5/8 inch was the maximum possible shank length to assure nonpenetration of the deck. However, as a 7/8 inch roofing nail was the shortest stock nail, we were committed to this fastener. We all realize that there are nail manufacturing tolerances, and that mechanics nailing techniques vary sufficiently so that as many nail points would probably break through the underside of the plywood as would not. At best, this was a makeshift specification, but from past experience we knew that only readily available fasteners should be specified.

The question might well be asked why staples were not considered. It is true that a 3/4 inch staple with divergent points, allowable under the Federal Housing Administration Bulletin No. 25, would be satisfactory, but it is not practical to require a power unit to drive staples for so limited an area or, in many cases, at isolated or individual building sites. Incidentally, this matter of hand versus power stapling is a subject worthy of further investigation.

Another problem is encountered with plywood decks in the application of built-up roofing. As spans increase and plywood thicknesses decrease, although still structurally sound, the resiliency or "bounce" of the deck makes nail driving difficult. The roofing nails must be secured through metal roofer's caps, and the initial resistance to driving, together with the springiness of the deck, discourages the mechanic sufficiently to incline him to skip nailing entirely. Fastening to plywood decks is still a very real and urgent problem.

At one time, the exterior finish of industrial buildings was required simply to cover the process going on in the buildings, offer reasonable protection from the elements, and provide suitable working conditions. In many cases thay are architecturally designed and, in the interest of aesthetic appearance, the architect is concerned with the elimination of all unsightly fastener heads of any kind. For the application of sheet materials to sidewalls over a nailable base, we have used nails painted to match the color of the particular siding units. Checkered patterns have been embossed on nailheads prior to painting, on the theory that the raised portion of the grid would absorb hammer blows and, if any paint were chipped-off, it would be held to a minimum. As the durability of paint coatings has improved, the head deformation has been eliminated. This sounds workable, but all too often the nail is hit on an angle and this either chips the coating from the head or, at best, damages the color coating so that the nail in its driven position is anything but invisible. We have seen samples of small, colored, snap-on fasteners, designed to reduce the prominence of the fastener heads. We also understand that plastic nails are being developed which are integrally colored to match whatever material is to be employed. This problem is not only of importance in exterior work but also in interior application.

As previously stated, this paper is not intended as an indictment of the fastener industry. It is rather a constructive attempt on the part of a building materials manufacturer to better acquaint others with our problems. Cooperation between the fasteners and materials industries has always been excellent -- after all, neither could stay in business long without the other. As we continue to work together solving our common problems, we may, like our naive ancestors of Ancient Roman days, eventually be sure that once we fasten our products to any base whatever they will never return to haunt us again.

Fastening of Roofing to Plywood

By David Countryman, Douglas Fir Plywood Association

Abstract: This paper describes tests of plywood as a nailing base for roofing, resulting in recommendations for fastening of common roofing materials to plywood. Tests described were conducted with wood, asphalt and asbestos-cement shingles, and asphalt built-up roofing, using a variety of nails. A test was also made with staples. The tests showed an advantage in holding power for the deformed shank nail over the smooth shank nail and found a ring shank nail superior to the screw-type fastener for roofing.

WOOD HAS BEEN USED as a roof sheathing material for so many years in this country that its performance is accepted without question. Typically, wood sheathing has meant boards, nominally 1 inch thick, actually closer to 3/4 inch. However, it was only some 25 years ago that plywood first made its appearance as a roof sheathing material. It was generally acknowledged that large panel size and dimensional stability made it an ideal base material for application of all types of roofing. However, because it was used in thicknesses less than the 3/4 inch to which the trade was accustomed in board sheathing, there were some questions raised at first as to the nail-holding ability of plywood.

It was certainly reasonable that such questions should arise, since the plywood thicknesses generally used were 5/16 inch and 3/8 inch. Such thicknesses were possible because the plywood was designed closer to actual end-use requirements, based on stiffness and strength under design and erection loads.

All materials manufacturerers who develop new products or new uses know that acceptance is greatly simplified if they can first prove performance equivalent to the traditional material. The traditional material may perform at a much higher level than necessary, but unless there are actual performance specifications available for the use in question, it is very difficult to prove what level of performance is adequate. We believe that all in the building materials field will agree there is a pressing need for such performance specifications.

Returning to the nail-holding power of plywood as a roof base, with no performance specifications to meet and no design require-

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ments other than perhaps, calculated uplift loads from wind, efforts were made to compare the performance of plywood with that of boards. Since the same type of fasteners were used in both, and since both boards and plywood were composed essentially of the same type of material, the "equivalency" was not always readily demonstrable.

However, there were enough differences between plywood and boards so that some factors were pertinent and could be cited in comparisons. First, plywood has fewer joints. Nails driven into or close to such joints may have impaired holding power in boards, due to the possibility of splitting. Plywood, on the other hand, can be nailed very close to the edge without splitting.

Plywood has no through defects. Knotholes are never aligned in all three plies -- rarely in two -- so that all nails driven have some holding power, even the few that may strike a void.

Plywood is always kiln-dried in manufacture, while boards are commonly used unseasoned. Drying after nailing causes a substantial loss in holding power, as much as 75% according to the U.S. Forest Products Laboratory. Of course, there is no guarantee that the plywood will remain in a dry condition prior to roofing, but a prolonged soaking is generally required to get it up to the fiber saturation point. Thus, while its dryness is not positively assured, in the majority of cases it is actually dry.

Finally, the species used in plywood is Douglas fir, whereas boards of less dense species are generally accepted without question as roof sheathing. The basic nail-holding power of such species, according to the U. S. Forest Products Laboratory formula, is as little as half that for Douglas fir.

Thus, fir plywood is likely to produce fewer defective nails, show less deterioration of its holding power and innately better holding power than many species commonly used and found satisfactory in the form of boards. Such facts, although theoretically sound, lack the authenticity of actual testing. For that reason, a substantial number of tests have been run over a period of years as the need developed in connection with the various roof covering materials.

TESTING ROOFING FASTENERS

Wood Shingles

The first roofing material considered was wood shingles. Wood shingles are usually attached to the sheathing with two 3d smooth-shank nails per shingle, with shingles laid about 5 inches to the weather. Tests were made by the Douglas Fir Plywood Association (DFPA) on completely shingled panels approximately 3 x 4 feet with the shingles nailed to various sheathing materials (1). The load required to pull an 8" wide shingle from the center of the panel upward at 45° to the plane of the sheathing was 114 lb. when the sheathing material was 3/8'' plywood (minimum 97 lb.) and 111 lb. when the sheathing was 1'' Douglas fir (minimum 83 lb.) In similar panels after six months' exposure to the weather, a lumber-sheathed panel averaged 104 lb. with a minimum of 90 lb., while after two years' exposure the 3/8'' sheathed panel averaged 113 lb. with a minimum of 98 lb.

A subsequent test on a panel sheathed with 5/16'' plywood shingled with 2d nails and exposed for 10 years showed an average load of approximately 60 lb. per shingle.

Tests conducted by the Canadian Forest Products Laboratory on wood shingles and 5/16'' plywood with 3d nails gave results from 50% to 80% higher than when the sheathing material was 7/8'' pine boards.

Tests made at the U.S. Forest Products Laboratory on the nail-holding power of 3/8'' sheathing grade plywood selected from many sources, using 3d galvanized shingle nails, gave a load of 88 lb. per nail (average of 223 tests). This value cannot be compared directly with the loads cited above as required to pull shingles from a roof, but they do indicate the level of holding power required to pull a nail from plywood sheathing.

From such test data, as well as from observations extended over many years throughout the country, it is the conclusion of the DFPA that the conventional nailing schedule for wood shingles is satisfactory with 5/16'' and thicker plywood roof sheathing.

Asphalt Shingles

Tests on asphalt shingles were undertaken by the DFPA at about the same time wood shingles were tested. It was quickly found that with conventional nailing schedules the strength of the connection was limited by the strength of the shingle rather than the sheathing. When the tab of a 12" x 36", 210 lb. asphalt strip shingle was grasped and pulled upward from 5/16'' plywood sheathing, it resulted in tearing of the shingle around the nail. The magnitude of the load depended upon the diameter of the head. A 3/8'' head developed a load of 14.4 lb. while a 7/16'' head developed 17.3 lb. per nail. The values varied for different sizes and weights of shingles, but 25 lb. was about the upper limit.

On the other hand, the average load required to withdraw smooth-shank roofing nails directly from plywood varied with the plywood thickness and the nail gauge. For example, it required a load of 43 lb. to withdraw a 12 gauge galvanized nail from 5/16'' plywood, while a load of 51 lb. was required for an 11 gauge nail from 5/16'', and 67 lb. from 3/8'' plywood.

Tests have also been made at the U. S. Forest Products Laboratory on the holding power of 3/8'' Douglas fir sheathing grade plywood using a 1-5/16'', 11 gauge galvanized asphalt shingle nail (5). The 233 tests showed an average load of 103 lb. required to withdraw this nail. Even with nails driven as close as 3/8'' to the edge of the plywood and into a knothole, the minimum test value was 55 lb.

Although some degradation of the nail-holding power of the plywood may occur with passage of time, the strength of the shingle itself will also change as it is subjected to weathering and temperature changes. Since a nail with a 3/8" head has the necessary strength for attaching a shingle, it can be concluded that any sheathing which develops and maintains equal or superior nail-holding power is adequate in this respect. Therefore, it was concluded that 5/16" or thicker plywood was adequate roof sheathing for asphalt shingles conventionally nailed.

Asbestos-Cement Shingles

Asbestos-cement shingles appear to require a stronger connection to the sheathing than either wood or asphalt shingles. In moving, under the effect of varying moisture content, they may exert sizeable forces on the nails. The problem of determining the most satisfactory nail for plywood sheathing was investigated in terms of application of siding shingles, but results will be comparable for roofing shingles.

In this respect, the DFPA investigated the strength, initially and after various cycles of seasoning, of various types of nail shanks (2). Of some 19 nails tested, the two most promising were 12 gauge (.102") aluminum nails, 1-1/8" long. One of these, Nail No. 18, had a spiral shank with 5 heavy flutings making 1-1/4 revolutions per inch of shank. The other one, No. 19, was essentially a ring shank nail with two light flutings making 15 revolutions per inch, similar to the thread on a wood screw. Both nails developed excellent holding power and gave promise of performing equally.

To check their performance further, an 8' x 12' panel was built using 5/16" plywood sheathing and asbestos-cement shingles furnished by three different manufacturers. Half of these were applied with the spiral shank No. 18 nails, and the other half with the screw shank No. 19 nails. The panel was set up with a southern exposure and thoroughly soaked every morning for approximately 100 days during the summer.

At the end of this time none of the shingles were loose, nor was any warping or buckling evident, although considerable expansion and contraction were noted as they passed from the wet to dry cycle during the test period. However, all of the nails were checked by attempting to pry them out with the tip of a screwdriver, and of the 87 nails of each type, 53 of the spiral shank No. 18, but only one of the screw shank No. 19 nails could be forced out as far as 1/8". The spiral shank nails unscrewed as they withdrew, which might not be true of their action if they had been restrained by friction of the shingle. Nevertheless, it was concluded that the lower pitch screw shank nails were preferable, and this is the type recommended for asbestos-cement shingles with plywood sheathing.

Built-up Asphalt Roofing

Built-up asphalt roofing has been used for many years over 3/8" and thicker plywood without special consideration for nailing requirements, both for residential roofing and, on the West Coast, for industrial buildings. Plywood 5/8" and thicker has been required when the roofing was bonded. More recently the major roofing companies have become interested in the use of 3/8" and 1/2" plywood as a base for bonded built-up roofing. Here, their primary interest has been in the nail-holding power of the plywood and its effect on the life of the roofing.

Again, the question was raised as to the most effective type of nail for this use. The DFPA undertook tests to answer this question, having first determined from members of the Asphalt Roofing Industry Bureau's Committee on Built-Up Roofing that the required holding power should be at least 30 to 40 lb. per nail. The approach was to compare the holding power of nails having various types of shanks with the load required to pull the head through the built-up roofing.

For built-up roofing the head of the nail is generally extended to approximately 1" diameter, or in some cases 1" square. This is sometimes accomplished with the addition of an auxiliary tin cap. Since the number of plies of felt used in a built-up roof varies with the duration of the bond, the nails may be driven through from one to five layers of felt. The loads required to pull the heads through the roofing at room temperature are shown in Table 1, for a 1" diameter head range from a minimum of 45 lb. with a single ply to a maximum of 194 lb. for four plies. The tin cap was found to have a maximum strength of 126 lb. with 5 plies before the nailhead pulled through the cap. The average load required to pull a 1" nailhead through a 15 lb. felt was a maximum of 20 lb., and through a 30 lb. felt was a maximum of 30 lb. The first ply of roofing is most vulnerable to pull-through of the nailhead, with its strength averaging 69 lb. with a 1" tin cap when four additional plies are hot-mopped to it. Thus, plywood nail-holding values higher than 69 lb. would be expected to develop the full strength of the first layer of felt.

In all, some 15 types of fasteners were tested (3) in both 3/8" and 1/2" Douglas fir plywood, and 5 of the most promising types selected for additional investigation. The five nails were further subjected to humidifying and drying cycles in 3/8" Douglas fir plywood. The exposure consisted of driving the nails into plywood having a moisture content of 17%, then drying it to approximately 10%. All of the nails averaged at least 90 lb. after being subjected to one, two, and three of these cycles. In other words, all nails were stronger than the strength developed by a 1" head when driven through the first two plies of a built-up roof.

All five of the nails had annular ring shanks, and ranged in gauge from .100" to .150". The number of rings per inch was generally 22 to 24, although one nail had 36. Two of the nails incorporated either a 1'' round or a 1'' square head, while the others required tin caps to develop their maximum strength.

TABLE 1 -- TESTS ON NAILHEADS PULLED THROUGH SUCCESSIVE LAYERS OF FELT IN A 20-YEAR ROOF

	Number of Plies[1]				
Nail	1	2	3	4	5
	(Withdrawal loads in pounds)				
B 1'' Square Head	61	100	126	150	177
D 1'' Diam Head	45	84	99	194	120
L 1'' Diam Tin Cap	69	78	87[2]	91[2]	126[2]

[1] 5-ply built-up roof with nails driven through number of plies as noted.

[2] Nail pulled through tin cap.

Some of the other fasteners also gave excellent results, although the five selected appeared to be superior, and consequently are recommended for the premium construction desired where roofs are to be bonded. Where this is not the case, the other may be entirely suitable. It is noteworthy that most of them exceeded the target value of 30 to 40 lb. per fastener by substantial amounts.

FACTORS AFFECTING HOLDING POWER

The more available test data are examined the more evident it becomes that there is a tremendous variation in the holding power of various fasteners. Even without regard to variations in types of fasteners, particularly their shanks, the effect of moisture content conditions alone can cause manifold changes in holding power.

Referring to Table 2, taken from DFPA Laboratory Report No. 61 (2), it can be seen that the holding power of a nail in plywood at a high moisture content (18 to 24%) is substantially more than that at a low moisture content (6 to 7%). For example, the smooth shank 13 gauge nail held 71 lb. at a high moisture content, but only 17 lb. at the low value. As the moisture content was cycled by soaking and drying, the fastener would regain its holding power at the high moisture content and lose it again as the moisture content was reduced.

TABLE 2 -- EFFECT OF CYCLIC MOISTURE CONTENT CHANGES ON NAIL-HOLDING POWER OF 5/16" PLYWOOD

Nail Number and Description	Plywood Moisture Content[1]					
	High	Low	High	Low	High	Low
	(Withdrawal loads in pounds per nail)[2]					
No. 17 Smooth-shanked, 13 ga.	71.5	20.4	59.5	24.5	70.4	
(.092") blued steel		16.6	41.2	26.0	56.6	27.1
No. 1 File-shanked (13 light flutings, 1 rev. per in.)	80.4	40.5	54.8	33.0	61.9	
12 ga. (.106") aluminum		28.4	39.9	25.0	45.1	26.4
No. 18 Spiral-shanked (5 heavy flutings, 1-1/4 rev. per in.)	87.8	51.3	69.6	59.7	72.8	
light 12 ga. (.102") aluminum		46.6	54.4	54.4	61.5	47.5
No. 19 Screw-shanked (2 light flutings, 15 rev. per in.)	105.0	44.2	89.1	43.4	85.5	
light 12 ga. (.102") aluminum		67.7	57.1	38.5	69.9	40.3

[1] High moisture content is 18-24%. Low moisture content is 6-7%.
[2] Each item is the average of 16 tests.

The same was true of the deformed shank nails, although usually to a lesser degree. In fact, reference to the data in Table 3, taken from DFPA Laboratory Report No. 87 (3), shows a remarkable degree of consistency for the ring shank nails A, B, C, D, and E, when driven and cycled between moisture contents of 17% and 10%. These conditions were obtained by exposure to varying humidities, rather than soaking and forced drying, as in the previous case, and may be more representative of the actual conditions.

It is also evident that nails driven when the plywood is at a high moisture content (18 to 24%) and then cycled develop generally higher loads than those driven when the plywood is extremely dry (6 to 7%) and then cycled through an equivalent range. It may be concluded that the nail holding power of a plywood roof deck will not suffer -- indeed may actually improve somewhat -- if it has been exposed to damp weather before the roof is laid. Within the less extreme ranges of 10 to 17% cycles, there is generally a small advantage if the nail is driven in the dryer condition.

Nails driven through plywood sometimes cause some splintering of the bottom ply, localized around the nail. This splintering is a phenomenon of the material, and whether it occurs or not apparently has little effect on the holding power of the fastener. It occurs to some extent even with staples, and with nails having needle points.

TABLE 3 -- SUMMARY OF WITHDRAWAL TESTS ON ROOFING NAILS IN 3/8" DOUGLAS FIR PLYWOOD SUBJECTED TO HUMIDIFYING AND DRYING CYCLES

Nail and Description	Condition[1]					Average
	1	2	3	4	5	of 2, 4, 5
	(Average withdrawal loads in pounds)[2]					
A -- 3/4" x .130" (Annular Ring Shank) 24 rings/in., bright steel	109	114	120	112	117	114
B -- 1" x .105" (Annular Ring Shank) 22 rings/in., bright steel	91	126	103	104	107	112
C -- 1" x .150" (Screw Shank) 36 threads/in., aluminum	109	78	128	81	112	90
D -- 7/8" x .100" (Annular Ring Shank) 22 rings/in., bright steel	96	97	84	97	91	95
E -- 1" x .140" (Annular Ring Shank) 24 rings/in., bright steel	107	122	107	114	107	114
F -- 1" x .120" (Screw Shank) 24 threads/in., aluminum	100	73	101	73	71	72
G -- 7/8" x .102" (Screw Shank) 32 rings/in., aluminum	86	69	98	65	67	67
H -- 7/8" x .105" (Smooth Shank) Roofing Nail, bright steel	60	49	67	31	57	52
J -- 1-1/8" x 16 ga. (Staple) bright steel	47	26	42	27	37	30

[1] Condition 1 -- Nails driven at 17% moisture content and withdrawn immediately.
2 -- Nails driven at 17% moisture content and withdrawn at 9.7% moisture content.
3 -- Nails driven at 9.7% moisture content and withdrawn immediately.
4 -- Nails driven at 17% moisture content, plywood dried to 9.7%, wetted to 17%, dried to 9.7%, and nails withdrawn (two drying cycles).
5 -- Like 4 above, but three drying cycles.

[2] Each item in Columns 1-5 is the average of 18 tests.

Voids

The sheathing grade of plywood permits limited knots and holes in both face and core veneers, some of which will be penetrated by nails when the roofing is applied. Some limited data on the effect of these defects in nail-holding power are available (1, 5) for both asphalt and wood shingle nails. Combining and summarizing these data, it is found that a nail penetrating a knot in the face of the plywood develops 98% of the strength of a nail in clear material (10 tests). A nail penetrating a hole in the face develops 65% of the strength of clear material (32 tests). A nail penetrating a hole in a core develops 39% of the strength of clear material (29 tests). These values were developed for plywood made of 3 plies of equal thickness. Although the likelihood of nails penetrating holes depends on the actual grade of veneer in the plywood, there is probably less than 1% chance that it will occur.

Species

The use of species other than Douglas fir is increasing rapidly, although it is still a minor factor. Mechanical properties, including nail holding, vary with the species of wood, being generally less for materials having lower specific gravity. There have been some tests made to determine whether the nail-holding power of such plywood will affect its use as compared with Douglas fir.

It may be noted parenthetically that interchangeability has been achieved between Douglas fir and those species listed under Group 1 in the Western Softwood Plywood Commercial Standard, USCS 122-60, as regards the normal sheathing application, by adjusting the veneer construction and by adding 1/32'' to the nominal thickness of the panel. This provides equivalent stiffness along the grain, and to some extent at least, adds to the nail-holding power.

DFPA Laboratory Report No. 87 (3) reports tests on the 5 ring shank nails recommended for built-up roofing using 3/8'' Group 1 Western softwood plywood. Nails were driven and pulled at 10% moisture content and the average load of the 5 nails was three-fourths that of the same nails pulled from Douglas fir plywood, but average 80 lb., or at least twice the required value.

Some additional tests were run at the Oregon Forest Research Center, using 12 gauge asphalt shingle nails and 5/8'' plywood made of various species. While the Douglas fir held an average of 128 lb., the West Coast hemlock and Pacific silver fir held respectively 154 and 112 lb. This series indicates a relatively better performance by the Western softwood Group 1 species. However, the results of both series indicate the possibility of some reduction in values for Group 1 species, the reduction being on the order of one-eighth to one-fourth below Douglas fir. Where the latter possesses excess capacity, the Group 1 species may ordinarily be used with the same nailing schedule. Otherwise, an adjustment in the nailing schedule is indicated.

Deformed Shank Nails

Where exceptionally high holding power is desired, the deformed shank nail offers an advantage over the smooth shank. A ring shank nail has been found superior to a screw-type fastener for roofing, as the roofing does not offer sufficient resistance to "unscrewing" of the nail as it starts to back out. Although many tests have been run on the holding power of such fasteners, apparently no general formula has yet been developed that can predict their strength. However, the FPL nail-holding formula is undoubtedly too conservative. One of the principal advantages of ring shank nails is that their holding power does not fluctuate as greatly as does that of smooth shank nails with moisture content changes. The use of these nails has been of considerable help in developing adequate schedules for fastening roofing to plywood sheathing.

Staples

Staples have become an increasingly popular method of attaching roofing because of the speed and convenience of using an air-operated tool. They are frequently used with asphalt shingles, where a 1" wide crown staple is required; also with built-up asphalt roofing in conjunction with a tin cap.

The Minimum Property Standards of the Federal Housing Administration (FHA) permit 16 gauge staples with a 1" crown width and a minimum over-all length of 3/4". Six staples are required for a 36" strip shingle, and special precautions are required to insure that the staple does not cut into the shingle. Available tests indicate that, just as with the asphalt roofing nail, the limiting strength of the connection is the tearing strength of the asphalt shingle at the staple crown. Generally, the 1" crown staple appears to develop slightly less strength in the shingle than a 3/8" head roofing nail. This deficiency is overcome by the use of more staples per shingle. A 16 gauge staple with 1/2" legs develops more holding power in 3/8" plywood than does its head in the shingle; increasing the legs to 5/8" develops holding power equal to two or three times the strength of the shingle in 3/8" plywood. Apparently, there is nothing to be gained by requiring a 3/4" minimum length of leg, since that part of the leg which penetrates through the back of the sheathing contributes nothing to the holding power.

Just as with nails, the effect of moisture content changes on staples is substantial. For example, a 16 gauge staple driven through 3/8" Douglas fir plywood lost one-fourth to one-half of its holding power when cycled between 17% and 10%.

Nail Penetration

Most roofing fasteners usually penetrate through the undersurface of wood roof sheathing. This is particularly true if the sheathing is plywood only 3/8" thick. Occasionally, the question arises as to whether such protruding metal fasteners may be conducive to condensation by conducting heat to the cold outside air. Condensation on nail points can be averted entirely by adequate attic ventilation, so that the humidity of the air is not allowed to build up to an objectionable level. Such ventilation, of course, is necessary anyway in order to prevent long-term damage and dry rot in the wood portions of the building.

For example, in 1960 a survey was made of 10 different builders who used 3/8'' plywood roof sheathing for 1349 homes in the states of North Dakota, Minnesota, and Wisconsin. The homes ranged up to 12 years in age, and all were ventilated in accordance with good practice. The builders reported not one complaint or problem due to condensation on the nail points, and no difficulty due to inadequacy of roof fastening.

Sometimes it is desirable to prevent the nail point from protruding from the underneath surface of the plywood because of objectionable appearance. This is desirable where the overhanging eave is exposed, for example, or where the roof sheathing forms the finished ceiling of an inhabitated area. In these cases it is usually difficult to develop adequate holding power with conventional nailing schedules. However, in some cases staples having 1/2'' legs have been used with 3/8'' plywood with no difficulties reported. In other cases, 5/8'' ring shank nails have been used with 1/2'' plywood. Tests on the latter indicate reasonably good holding power (about 60 lb.), although the short length may be somewhat difficult to handle and nail.

Actually, it has been found that penetration of the nail completely through the sheathing improves the durability of a wood shingled roof. A survey made by Purdue University Agricultural Experiment Station (4) presents the results of 750 applications of wood-shingled roofs in 12 states, averaging 23 years of age. It was conclusively determined from these observations that roofs in which the nails penetrated through the board sheathing had fewer warped and loose shingles than those in which the nails did not penetrate.

SUMMARY

In general, the acceptance of plywood as a nailing base for roofing has come about gradually. While it is difficult to estimate the total amount of plywood now in use for roof sheathing in this country, it certainly runs into several billions of square feet. There are records of a substantial number of roofing applications over plywood that range up to 20 and 25 years. Many plywood sheathed residences have been in the path of the hurricanes that occur along the south and east coasts of the country, and performance has been very creditable.

As a result of the substantial amount of testing described here, and of field experience acquired at the same time, it is possible to make valid recommendations regarding the fastening of common roofing materials to plywood sheathing, with every confidence that their performance will be entirely satisfactory.

REFERENCES

1. Douglas Fir Plywood Association. Test Data on Shingles Nailed to Plywood Sheathing. DFPA Laboratory Report No. 26, 1943 (out of print).
2. Douglas Fir Plywood Association. An Investigation of Nails for Attachment of Asbestos-Cement Shingles to 5/16'' Douglas Fir Plywood. DFPA Laboratory Report No. 61, 1953.
3. Douglas Fir Plywood Association. Holding Power of Roofing Nails in 3/8'' and 1/2'' Plywood. DFPA Laboratory Report No. 87, 1961.
4. Purdue University, Agricultural Experiment Station. A Study of Farm Building Materials on Farms in the North Central Region. Station Bulletin 601, 1954.
5. U.S. Forest Products Laboratory. Mechanical Properties of Douglas Fir Plywood of D Grade Veneer and Veneer Containing White Pocket. U.S. FPL Report No. P&E-170, 1958.

Fastening of Plywood in Diaphragm Construction for Load Transmission

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Abstract: Test data are presented from a series of three tests over a three-year period to show that plywood sheathing can be more effectively applied with properly threaded nails of shorter length and extra-large diameter. Performance of common wire nails was compared to that of a variety of barbed, helically threaded and annularly threaded nails in terms of immediate and delayed axial withdrawal resistance, lateral load transmission at small joint deformation, and ultimate lateral load-carrying capacity. The data can form a basis for derivation of design data for these threaded nails under given use conditions.

SHEATHING, as well as combination sheathing and siding, is being employed more and more to transmit loads in lieu of secondary supplementary framing such as diagonals and ribbons, particularly in construction designed to resist earthquakes and wind storms. In such construction, the sheathing is used as a diaphragm to transmit both static and impact forces within its own plane, in vertical walls, horizontal floors and ceilings, and horizontal or inclined roofs. Diaphragms are also used for the construction of folded plate structures, hyperbolic paraboloids, and vaults of various types.

Because of the advantages brought about by the use of large Douglas fir plywood panels, plywood diaphragm sheathing is being used extensively (3). Its fastening to framing and rafters has been standardized over a number of years. According to Federal Housing Administration minimum requirements, 5/16" and 3/8" plywood sheathing should be fastened with 6d common wire nails, and thicker plywood with 8d nails. Other recommendations for nailing plywood diaphragms advanced by the Douglas Fir Plywood Association and the Uniform Building Code indicate that 1/4" and 5/16" plywood should be fastened with 6d, 3/8" plywood with 8d, and 1/2" plywood with 10d common wire nails, with the nail spacing along the plywood panel edges ranging from 3" to 6" and at intermediate bearings not to exceed 12". If smaller common wire nails are used, the lower design values recommended for these nails are applicable.

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However, the design data for plywood panels fastened according to these provisions cannot take full advantage of the design strength of the plywood, principally because of the limitations of common wire nails. During seasoning of the lumber into which they are driven, plain-shank nails "lose a major part of their withdrawal resistance. In seasoned wood that is not subjected to appreciable moisture content changes, the withdrawal resistance of (common wire) nails also may diminish with lapse of time" (5, pp. 167-9). Furthermore, any long plain-shank nails tend to back out as a result of temperature changes to which most of the sheathing and sheathing nails are repetitively exposed. Thus, the generally accepted design values for these fasteners are relatively low. In turn, they limit the design values which can be allowed for load transmission by the plywood panels.

In order to overcome these limitations and take full advantage of the potential strength of plywood panels, the suggestion was made that they be fastened with relatively short, large-diameter, properly threaded nails, made either of bright low-carbon steel or of bright or hardened high-carbon steel (1).

These nails should be as short as possible to reduce nail protrusion and popping which otherwise result from changes in moisture content of the lumber, and from exposure to extremes in temperature. The nails should be of large diameter to provide maximum joint rigidity and to transmit relatively large lateral loads in plywood and lumber. They should be properly threaded to provide permanently high withdrawal resistance, since slight loosening of the nail seriously reduces the effectiveness of the joint. If low-carbon steel nails do not provide the desired stiffness and rigidity, they should be of high-carbon steel, either non-hardened (stiff-stock), or hardened, i.e., heat-treated and tempered. To allow tight fastening of the plywood with a minimum of effort, a clearance or smooth-shank section is provided along the nail shank, between nailhead and threads. The incorporation of such a clearance results in a tight fit of the plywood around the nail shank. This tightness, and a tight seat of the helically threaded shank in the wood to which the plywood is fastened, result in a minimum slip during load transmission by the nail.

These nails, with helical threads along the lower part of the shank, are used for fastening plywood gusset plates for nailed trussed rafters (6). Provided with annular threads and made of a non-rusting nickel alloy of copper, iron and manganese, they are employed in boat building (7). Provided with annular threads and made of corrosion-resistant silicon bronze, these nails were used successfully to fasten the experimental, 1/2" x 4' x 8' plywood decking of the National Association of Home Builders Research Home of the Year (4).

EXPERIMENTAL DATA

In order to determine the effectiveness of the various nails used in the fastening of Douglas fir plywood of 3/8", 1/2", 5/8", 3/4" 7/8" and 1" thickness, fully comparative tests were performed with the following types of nails:

(a) 8d -- 2 1/2" x 0.129", 10d -- 3" x 0.145", 12d -- 3 1/4" x 0.148" common wire nails, with counts of 99, 62, and 60 nails per pound, respectively.
(b) 2" x 0.148", superficially barbed nails, with a count of 98 per pound.
(c) 1 1/2" x 0.135" and 1 1/2", 1 3/4", 2", and 2 1/2" x 0.148" bright low-carbon steel and hardened high-carbon steel, plain-shank, helically threaded (with medium or short lead angle), and annularly threaded nails, with counts of 156, 132, 115, 102, and 82 nails per pound, respectively. These nails, were provided with 1/4" or 1/2" clearance between head and threads, with a 5/16" flat, and slightly countersunk heads and a medium diamond point.[1]

The nails were hammer-driven through sheathing-grade Douglas fir plywood into green or air-seasoned Douglas fir or southern pine lumber. They were tested for their immediate and delayed axial withdrawal resistance, and for lateral load-carrying capacity, that is, their ability to transmit shear loads from plywood of given thickness to supporting lumber, by applying the lateral load perpendicular to the face grain of the plywood and to the grain of the lumber. The lateral edge distance of the nail in the plywood amounted to either 3/8" or 5/8".

The tests were performed immediately after nail driving, or after five-week seasoning of the nailed assembly in 50% relative humidity at 70° F temperature. Quadruple, quintuple or sextuple tests were run on all nails under given conditions, following the previously established matching and testing procedures (2). The rate of loading, with an electomatic testing machine, was 0.100 per minute throughout the test performance. The test progress during lateral loading of the joints was recorded automatically in load-deformation curves. The lateral load transmission at 0.050" and 0.100" total joint deformation was determined from the load-deformation curves.

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[1] The annularly threaded nails with zero lead angle, helically threaded nails with medium lead angle, helically threaded screwnails with short lead angle, and relatively short nails with extra large shank diameter are products of the manufacturer under whose sponsorship this investigation was performed. The data presented in this report apply only to the nails subjected to tests and cannot be applied to nails of different design and manufacture without corrōborating test data.

TEST RESULTS AND CONCLUSIONS

Three separate series of tests were performed in the course of a three-year period. Results are outlined below.

Test 1. 1/2" Plywood Sheathing (8)

The nails shown in Figure 1 were driven through 1/2" Douglas fir plywood of 0.52 oven-dry specific gravity and 9.4% moisture content into green southern pine of 0.48 oven-dry specific gravity and 29% moisture content. After five-week seasoning of the nailed test plank, its moisture content was 13%. Average test results are given in Table 1.

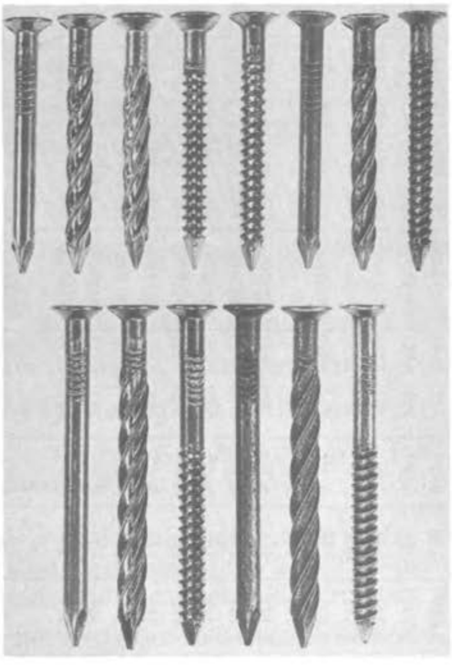

Figure 1. Top row, 1-1/2'' x 0.135'' and bottom row, 2'' x 0.148'' nails. Top row, left to right: low-carbon steel plain-shank nail; two helically threaded nails with medium lead angle; annularly threaded nail with zero lead angle; and helically threaded screwnail with short lead angle; hardened high-carbon steel plain-shank nail; helically threaded nail; and helically threaded screwnail.

A. Axial Withdrawal Resistance

To fasten plywood panels permanently tight to satisfactorily spaced and well jointed framing lumber, and thus, to prevent

TABLE 1 -- AVERAGE EFFECTIVENESS OF VARIOUS TYPES OF STEEL NAILS IN FASTENING 1/2" DOUGLAS FIR PLYWOOD SHEATHING TO GREEN SOUTHERN PINE

Size of Nail	Type of Nail	Steel and Finish	Weight, g.	Count per Pound	Edge Distance	Withdrawal Resistance, lb.		Lateral Load-Carry. Cap., lb.		Lateral Load, lb., at			
										0.050" Def.		0.100" Def.	
						Imm.	Del.	Imm.	Del.	Imm.	Del.	Imm.	Del.
2-1/2" x 0.129"	Com. Wire	L Bright	4.442	101	3/8"	347(100%)	113(100%)	439(100%)	302(100%)	180(100%)	156(100%)	293(100%)	229(100%)
1-1/2" x 0.135"	Plain-Shank	L Bright	2.829	159	3/8"	142(41%)	38(34%)	291(66%)	315(104%)	162(90%)	164(105%)	227(77%)	232(101%)
1-1/2" x 0.135"	A	L Bright	2.824	159	3/8"	200(58%)	146(129%)	348(79%)	337(112%)	161(89%)	171(110%)	227(77%)	231(101%)
1-1/2" x 0.135"	A	L Bright	2.846	158	3/8"	182(52%)	127(112%)	328(75%)	325(108%)	180(100%)	178(114%)	252(86%)	250(109%)
1-1/2" x 0.135"	B	L Bright	2.844	158	3/8"	350(101%)	336(297%)	349(79%)	344(114%)	127(71%)	129(83%)	196(67%)	196(86%)
1-1/2" x 0.135"	C	L Bright	2.807	160	3/8"	344(99%)	319(282%)	365(83%)	376(125%)	103(57%)	121(78%)	187(64%)	195(85%)
1-1/2" x 0.135"	Plain Shank	H Hard.	2.832	159	3/8"	274(79%)	93(82%)	385(88%)	352(117%)	188(104%)	196(126%)	269(92%)	258(113%)
1-1/2" x 0.135"	A	H Hard.	2.767	163	3/8"	292(84%)	233(206%)	413(94%)	391(129%)	174(97%)	162(104%)	242(83%)	249(109%)
1-1/2" x 0.135"	C	H Hard.	2.761	163	3/8"	366(105%)	380(336%)	361(82%)	348(115%)	135(75%)	136(87%)	205(70%)	217(95%)
2" x 0.148"	Plain-Shank	L Dull	4.422	102	3/8"	345(99%)	60(53%)	375(85%)	283(94%)	228(127%)	181(116%)	286(98%)	242(106%)
2" x 0.148"	A	L Bright	4.455	101	3/8"	272(78%)	177(157%)	434(99%)	361(120%)	191(106%)	191(122%)	283(97%)	260(114%)
2" x 0.148"	C	L Bright	4.513	100	3/8"	569(164%)	538(476%)	427(97%)	359(119%)	131(73%)	142(91%)	223(76%)	219(96%)
2" x 0.148"	Plain-Shank	H Hard.	4.278	105	3/8"	417(120%)	93(82%)	458(104%)	406(134%)	235(131%)	201(129%)	335(114%)	294(128%)
2" x 0.148"	A	H Hard.	4.408	102	3/8"	573(165%)	411(364%)	468(107%)	405(134%)	210(117%)	189(121%)	320(109%)	277(121%)
2" x 0.148"	C	H Hard.	4.329	104	3/8"	616(178%)	569(504%)	374(85%)	365(121%)	148(82%)	149(96%)	244(83%)	246(107%)
2-1/2" x 0.129"	Com. Wire	L Bright	4.442	101	5/8"	--------	--------	446(100%)	322(100%)	189(100%)	178(100%)	286(100%)	254(100%)
1-1/2" x 0.135"	A	L Bright	2.846	158	5/8"	--------	--------	325(75%)	--------	113(60%)	--------	193(67%)	--------
2" x 0.148"	A	L Bright	4.455	101	5/8"	--------	--------	515(115%)	--------	178(94%)	--------	275(96%)	--------
2" x 0.148"	A	H Hard.	4.408	102	5/8"	--------	--------	564(125%)	505(157%)	150(79%)	170(96%)	252(88%)	269(106%)

KEY: A - Helically threaded nail; B - Annularly threaded nail; C - Helically threaded screwnail; H - High-carbon steel; L - Low-carbon steel.

buckling of the plywood sheathing, both the immediate and delayed axial withdrawal resistance of the fasteners should be as great as practical.

1. In comparison with the immediate and five-week delayed withdrawal resistance of the 2-1/2" x 0.129" (8d) common wire nail, the stout nails were found to be as effective as shown in the following tabulation:

	Withdrawal Resistance	
Nail Description	Immediate	Delayed
1-1/2" x 0.135" helically threaded nails	55%	120%
1-1/2" x 0.135" annularly threaded nail	101%	297%
1-1/2" x 0.135" helically threaded nail with short lead angle.	99%	282%
1-1/2" x 0.135" hardened helically threaded nail	84%	206%
1-1/2" x 0.135" hardened helically threaded nail with short lead angle	105%	336%
2" x 0.148" helically threaded nail	78%	157%
2" x 0.148" helically threaded nail with short lead angle	164%	476%
2" x 0.148" hardened helically threaded nail	165%	364%
2" x 0.148" hardened helically threaded nail with short lead angle	178%	504%

2. During five-week exposure, the holding power decreased as follows:
   (a) 2-1/2" common wire nail decreased 67%
   (b) helically threaded nails decreased on the average 28%
   (c) annularly threaded nail decreased 4%
   (d) helically threaded nails with short lead angle decreased on the average 5%.

3. On a basis of uniform weight of the nails, and in comparison with the holding power of the 2-1/2" common wire nail, the average immediate and delayed efficiency was:
   (a) bright helically threaded nails 0.8 and 1.7 times as great
   (b) hardened helically threaded nails 1.5 and 3.5 times as great
   (c) bright annularly threaded nail and helically threaded nails with short lead angle 1.6 and 4.6 times as great
   (d) hardened helically threaded nails with short lead angle 1.8 and 5.3 times as great.

In light of these data, optimum holding power may be obtained most efficiently with the helically threaded nails with short lead angle. The 1-1/2" x 0.135", and bright or hardened nails provide 2.8 or 3.4 times and the 2" x 0.148", and bright or hardened nails provide 5.4 or 5.0 times as great a holding power as the 2-1/2" common wire nail, soon after being driven into green and partially seasoned framing lumber.

B. Lateral load Transmission at 0.050" Total Joint Deformation and Lateral Load-Carrying Capacity

If the diaphragm sheathing is to provide maximum stiffness and rigidity, and if the diaphragm shear load is to be transmitted effectively and safely, both the immediate and delayed lateral load transmission at small joint deformations and the ultimate lateral load-carrying capacity should be high.

1. In comparison with the immediate and five-week delayed effectiveness of the 2-1/2" x 0.129" (8d) common wire nail, the stout nails performed as shown below:

	Load Transmission at 0.050" Joint Deform.		Lateral Load-Carrying Capacity	
Nail Description	Immediate	Delayed	Immediate	Delayed
1-1/2" x 0.135" helically threaded nails	94%	112%	77%	110%
1-1/2" x 0.135" annularly threaded nail	71%	83%	79%	114%
1-1/2" x 0.135" hel. threaded nail with short lead angle	57%	78%	83%	125%
1-1/2" x 0.135" hardened helically threaded nail	97%	104%	94%	129%
1-1/2" x 0.135" hard. hel. thr. nail with short lead angle	75%	87%	82%	115%
2" x 0.148" helically threaded nail	106%	122%	99%	120%
2" x 0.148" hel. threaded nail with short lead angle	73%	91%	97%	119%
2" x 0.148" hardened helically threaded nail	117%	121%	107%	134%
2" x 0.148" hard. hel. thr. nail with short lead angle	82%	96%	85%	121%

2. During five-week exposure, the effectiveness of the nails was found to have changed as follows:

Nail Description	Load Transmission at 0.050" Joint Deform.	Lateral Load-Carrying Capacity
2-1/2" common wire nail	87%	69%
helically threaded nails	97%	91%
annularly threaded nail	102%	99%
helically threaded nails with short lead angle	107%	95%

3. On basis of uniform weight of the nails, and in comparison with the immediate and five-week delayed efficiency of

the 2-1/2'' common wire nail, the stout nails performed as shown below:

Nail Description	Load Transmission at 0.050'' Joint Deform.		Lateral Load-Carrying Capacity	
	Immediate	Delayed	Immediate	Delayed
1-1/2'' helically threaded nails	1.5 times	1.7 times	---	---
1-1/2'' annularly threaded nail and helically threaded nail with short lead angle, and 2'' helically threaded nails	1.1 times	1.3 times	---	---
2'' helically threaded nails with short lead angle	0.8 times	0.9 times	---	---
1-1/2'' threaded nails	---	---	1.3 times	1.9 times
2'' hel. thr. nails with medium and short lead angles	---	---	1.0 times	1.2 times

In the light of these data, the optimum lateral load transmission at 0.050'' joint deformation may be obtained most efficiently with the 1-1/2'' helically threaded nails. The lateral load transmission of the helically threaded nails at 0.050'' joint deformation differs very little from that of the 1'' longer, 8d common wire nail. Mainly because of the difference in length, the efficiency of the helically threaded nails is 1.1 to 1.75, with an average of 1.4 times as great.

The ultimate lateral load-carrying capacities of the various types of tested nails also differ relatively little. Those of the threaded nails, in immediate and delayed tests, amount to 0.8 and 1.3 times, respectively, that of the 2-1/2'' common wire nail. However, in comparison with the efficiency of the 2-1/2'' common wire nail, the efficiency of the 1-1/2'' threaded nails is 1.7 to 2.1 times, with an average of 1.9 times as great, again due largely to difference in length.

C. Effect of Edge Distance

The lateral load-carrying capacity of plywood can be influenced by the distance between the nail shank and the edge of the plywood panel. If the framing consists of nominal 2'' lumber, this edge distance usually amounts to 3/8''. Test results presented in the previous paragraphs are based on such an edge distance, with the lateral load applied by the nail shank in a direction perpendicular to and toward the plywood edge.

If wider framing lumber is used, the distance between nail and plywood edge can be larger, and the previously presented test results on the lateral load-carrying capacity of nails in 1/2'' Douglas fir plywood may be too conservative. It should also be noted that at points where the plywood panel bears on intermediate members, the edge distance of the nails has no influence on the effectiveness of the joints.

In order to determine the influence of a slightly larger distance than 3/8'' between nail and edge of 1/2'' Douglas fir plywood, fully matched tests were performed with nails spaced 5/8'' from the plywood edge. Such an increase in edge distance from 3/8'' to 5/8'' did not increase the lateral load-carrying capacity of the 2-1/2'' common wire nail and 1-1/2'' bright helically threaded nail. However, it did increase the lateral load-carrying capacity of the 2'' bright and hardened helically threaded nails approximately one-fifth.

D. Conclusions

If properly threaded nails are used at given locations, instead of 2-1/2'' (8d) common wire nails, Douglas fir plywood sheathing of 1/2'' thickness can be fastened to green or partially-seasoned framing five times more effectively with the same weight 2'' x 0.148'' bright or hardened helically threaded nails with short lead angle. This can also be accomplished three times more effectively with one-third lighter 1-1/2'' x 0.135'', and otherwise identical nails. The efficiency of these threaded nails, on a uniform weight basis, may amount to approximately five times that of the 2-1/2'' common wire nail. If 2'' and 1-1/2'' helically threaded nails are employed for installing the sheathing, it can be fastened 1.2 to 3.6 times as effectively and 1.7 to 3.5 times as efficiently as with the 2-1/2'' common wire nails.

The design diaphragm shear load for this sheathing, based on the lateral load transmission at a relatively small joint deformation, is similar whether 2-1/2'' common wire nails or 1-1/2'' x 0.135'' or 2'' x 0.148'' helically threaded nails are used. However, the efficiency of these helically threaded nails can be 1-3/4 times as great as that of the 2-1/2'' common wire nails.

The sheathing described can transmit the same or, under given conditions, a slightly larger ultimate diaphragm shear load with the above threaded nails than with the 2-1/2'' common wire nails. Yet the efficiency, on a uniform weight basis, of the 1-1/2'' x 0.135'' threaded nails may be twice that of the 2-1/2'' common wire nails.

Test 2. 3/8'' Plywood Sheathing (9)

The nails shown in Figure 2 were driven through 3/8'' Douglas fir plywood of 0.49 oven-dry specific gravity and 7.1% moisture content into air-seasoned southern pine of 0.56 oven-dry specific gravity and 18.5% moisture content. After five-week seasoning of the nailed test plank, its moisture content was 12.6%. Average test results are given in Table 2.

TABLE 2 – AVERAGE LATERAL LOAD-CARRYING CAPACITY OF VARIOUS TYPES OF STEEL NAILS IN FASTENING 3/8" DOUGLAS FIR PLYWOOD SHEATHING TO AIR-SEASONED SOUTHERN PINE LUMBER

Size of Nail	Type of Nail	Steel and Finish	Weight in Grams	Count per Pound	Edge Distance	Lateral Load-Carrying Capacity, lb.		Lateral Load, lb., at			
								0.050" Deformation		0.100" Deformation	
						Immediate	Delayed	Immediate	Delayed	Immediate	Delayed
2" x 0.103"	Common Wire	L. Bright	2.242	201	3/8"	259 (100%)	182 (100%)	175 (100%)	130 (100%)	225 (100%)	161 (100%)
2½" x 0.129"	"	" "	4.442	101	"	394 (152%)	287 (158%)	240 (137%)	166 (128%)	295 (131%)	233 (145%)
1½" x 0.135"	Plain-Shank	" "	2.829	159	"	323 (125%)	288 (158%)	228 (130%)	170 (131%)	277 (123%)	247 (153%)
"	Hel. thr.	" "	2.824	"	"	379 (146%)	312 (171%)	216 (123%)	142 (109%)	298 (132%)	232 (144%)
"	Plain-Shank	H Hardened	2.832	"	"	416 (161%)	326 (179%)	230 (131%)	178 (137%)	313 (139%)	260 (161%)
"	Hel. thr.	" "	2.767	163	"	360 (139%)	305 (168%)	(177)(101%)	173 (133%)	(266)(118%)	257 (160%)
2" x 0.148"	Hel. thr.	L Bright	4.455	101	"	297 (115%)	287 (158%)	223 (127%)	177 (136%)	274 (122%)	253 (157%)
"	Hel. thr.	H Hardened	4.408	102	"	361 (139%)	345 (190%)	214 (122%)	166 (128%)	307 (136%)	274 (170%)
2" x 0.103"	Common Wire	L Bright	2.242	201	5/8"	299 (100%)		198 (100%)		235 (100%)	
2½" x 0.129"	"	" "	4.442	101	"	449 (150%)		260 (131%)		303 (129%)	
1½" x 0.135"	Hel. thr.	" "	2.824	159	"	547 (183%)		233 (118%)		316 (134%)	
"	Plain-Shank	H Hardened	2.832	"	"	441 (147%)		253 (128%)		335 (143%)	
"	Hel. thr.	" "	2.767	163	"	546 (183%)		248 (125%)		334 (142%)	
2" x 0.148"	Hel. thr.	L Bright	4.455	101	"	446 (149%)		217 (110%)		305 (130%)	
"	Hel. thr.	H Hardened	4.408	102	"	522 (175%)		252 (127%)		367 (156%)	

KEY: H – High-carbon steel; L – Low-carbon steel.

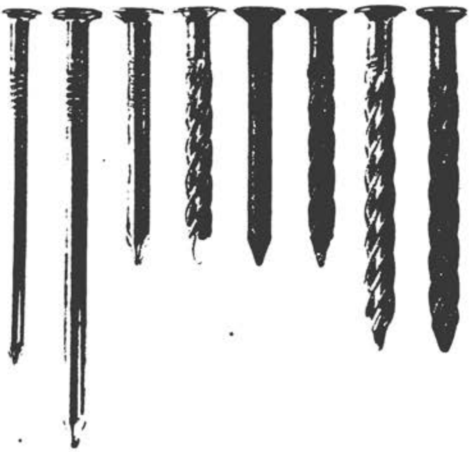

Figure 2. Left to right: 2'' x 0.103'' and 2-1/2'' x 0.129'' common wire nails; 1-1/2'' x 0.135'' low-carbon steel, plain shank and helically threaded nails; same two nails made of hardened high-carbon steel; and 2'' x 0.148'' low-carbon steel and hardened high-carbon steel helically threaded nails.

A. Lateral Load Transmission at 0.050'' Total Joint Deformation and Lateral Load-Carrying Capacity

The lateral load-carrying capacity of almost all of the tested nails was limited by the edge distance of the plywood, regardless whether the edge distance was 3/8'' or 5/8''. In the latter case, larger load transmission was possible. Consequently, the test data obtained are applicable to nails located 3/8'' and 5/8'', respectively, from the plywood edge. If the nails are spaced farther from the edge or in the plywood field, greater load transmission by these nails may be expected.

An exception is the 2'' common wire nail. Its delayed load transmission, if spaced 3/8'' from the plywood edge, and its immediate load transmission, if spaced 5/8'' from the edge, were limited by the withdrawal resistance of this nail. Consequently, greater load transmission cannot be expected from the 2'' common wire nail, even if the distance from the plywood edge should be greater than 5/8''.

1. In comparison with the immediate and 5-week delayed effectiveness of the 2'' x 0.103'' (6d) common wire nail, the stout nails were found to be as effective as shown as follows:

Nail Description	Effectiveness at Given Edge Distance					
	Load Transmission at 0.050" Joint Deform.			Lateral Load-Carrying Capacity		
	Immediate		Delayed	Immediate		Delayed
	3/8"	5/8"	3/8"	3/8"	5/8"	3/8"
1-1/2" x 0.135" helically threaded nail	123%	118%	109%	146%	183%	171%
1-1/2" x 0.135" hardened helically threaded nail	---	125%	133%	139%	183%	168%
2" x 0.148" helically threaded nail	127%	110%	136%	115%	149%	158%
2" x 0.148" hardened helically threaded nail	122%	127%	128%	139%	175%	190%

A comparison of the effectiveness of the stout nails and the 2" common wire nail, which failed in shank withdrawal during delayed testing, while in all other cases the ultimate lateral load carrying capacity was limited by the 3/8" or 5/8" edge distance, shows that the stout nails provided:

(a) from 9% to 36% larger lateral load transmission at 0.050" joint deformation for 3/8" edge distance

(b) from 10% to 27% larger lateral load transmission at 0.050" joint deformation for 5/8" edge distance;

(c) from 15% to 90% larger ultimate lateral load-carrying capacity for 3/8" edge distance;

(d) from 49% to 83% larger ultimate lateral load-carrying capacity for 5/8" edge distance.

2. In comparison with the immediate and five-week delayed effectiveness of the 2-1/2" x 0.129" (8d) common wire nail, the stout nails were found to perform as shown in the following tabulation:

Nail Description	Effectiveness at Given Edge Distance					
	Load Transmission at 0.050" Joint Deform.			Lateral Load-Carrying Capacity		
	Immediate		Delayed	Immediate		Delayed
	3/8"	5/8"	3/8"	3/8"	5/8"	3/8"
1-1/2" x 0.135" helically threaded nail	90%	90%	86%	96%	122%	109%
1-1/2" x 0.135" hardened helically threaded nail	---	95%	104%	91%	122%	106%
2" x 0.148" helically threaded nail	93%	83%	107%	75%	99%	100%
2" x 0.148" hardened helically threaded nail	89%	97%	100%	92%	116%	120%

Hence, in comparison with the effectiveness of the 2-1/2" common wire nail, the stout nails provided:

(a) from 14% smaller to 7% larger lateral load transmission at 0.050'' joint deformation for 3/8'' edge distance;

(b) from 3% to 17% smaller lateral load transmission at 0.050'' joint deformation for 5/8'' edge distance;

(c) from 4% to 25% smaller immediate ultimate lateral load-carrying capacity for 3/8'' edge distance;

(d) from 0% to 20% larger delayed ultimate lateral load-carrying capacity for 3/8'' edge distance;

(e) from 1% smaller to 22% larger ultimate lateral load-carrying capacity for 5/8'' edge distance.

B. Effect of Edge Distance

1. In comparison with the immediate effectiveness of the tested nails with 3/8'' edge distance, the tested nails with 5/8'' edge distance were found to perform as shown in the following tabulation:

Nail Description	Load Transmission at 0.050'' Joint Deform.	Lateral Load-Carrying Capacity
2'' x 0.103'' common wire nail	113%	115%
2-1/2'' x 0.129'' common wire nail	108%	114%
1-1/2'' x 0.135'' helically threaded nail ...	108%	144%
1-1/2'' x 0.135'' hardened helically threaded nail	---	152%
2'' x 0.148'' helically threaded nail ...	97%	150%
2'' x 0.148'' hardened helically threaded nail	118%	145%

Hence, increase in edge distance from 3/8'' to 5/8'' increased the lateral load transmission at 0.050'' joint deformation from -3% to +18%, and the ultimate lateral load-carrying capacity from 14% to 15% for plain-shank nails and from 44% to 52% for helically threaded nails.

C. Conclusions

In light of the test data presented, any of the tested stout nails can replace the 2'' (6d) common wire nail for transmitting shear loads from 3/8'' plywood diaphragm panels to lumber framing. Wherever the ultimate lateral load transmission (after seasoning of the lumber to moisture equilibrium) is the criterion, the design loads can be increased 50% to 90%, depending upon the type of stout nail selected, whether it is a 1-1/2'' x 0.135'' or 2'' x 0.148'', bright low-carbon steel or hardened high-carbon steel, helically threaded nail.

If a 2-1/2'' (8d) common wire nail is specified for the above purpose, most of the stout nails tested can be used in place of the common wire nail, where the transmission of shear loads after seasoning of the nailed lumber is the criterion.

In case of a 5/8'' edge distance in 3/8'' plywood, instead of a 3/8'' edge distance, 50% larger shear loads can be transmitted by the stout helically threaded nails. For nails placed in the field of the plywood panel, the shear-load transmission may be larger.

Test 3. 3/8'' to 1'' Plywood Sheathing (9)

The nails shown in Figures 3 and 4, page 34, were driven through sheathing-grade Douglas fir plywood, which was selected by the Douglas Fir Plywood Association as fully representative of average production. Its physical properties are listed below:

Thickness	Oven-Dry Specific Gravity	Moisture Content
3/8''	0.52	6.0%
1/2''	0.51	6.8%
5/8''	0.50	7.1%
3/4''	0.52	7.1%
7/8''	0.54	7.5%
1''	0.50	7.0%
Avg.	0.51	6.9%

The nails were driven into air-seasoned 2'' x 6'' Douglas fir of 0.53 oven-dry specific gravity and 20.4% average moisture content for the performance of the withdrawal tests; and into air-seasoned 2'' x 10'' Douglas fir of 0.64 oven-dry specific gravity and 15.9% average moisture content for the performance of the lateral loading tests. During five-week seasoning of the nailed test planks, their moisture content was reduced from 20.4% to 11.5% and from 15.9% to 12.4%.

Average test results are given in Table 3, on page 35.

A. Axial Withdrawal Resistance --

1. A comparison of the effectiveness in withdrawal of the various types of nails of different lengths can be based on their withdrawal resistance in pounds per inch of shank penetration, as shown in the following tabulation:

	In Fastening of Plywood of Given Thicknesses															
	Immediate								Delayed							
Nail Description	3/8''	1/2''	5/8''	3/4''	7/8''	1''	Avg.	Gr. Avg.	3/8''	1/2''	5/8''	3/4''	7/8''	1''	Avg.	Gr. Avg.
2-1/2'' x 0.129'' common wire nail	165	146	---	---	---	---	156	156	81	86	---	---	---	---	84	84
3'' x 0.145'' common wire nail	---	---	203	---	---	---	203	176	---	---	97	---	---	---	97	81
3-1/4'' x 0.145'' common wire nail	---	---	---	161	141	200	167		---	---	---	82	76	70	76	
2'' x 0.148'' barbed nail	---	142	---	163	---	158	154	154	---	78	---	72	---	84	78	78
1-1/2'' x 0.135'' helically threaded nail	204	189	---	---	---	---	196	196	218	175	---	---	---	---	196	196
1-1/2'' x 0.148'' helically threaded nail	---	236	223	---	---	---	230	257	---	293	267	---	---	---	280	271
1-3/4'' x 0.148'' helically threaded nail	---	---	279	242	---	---	260		---	---	253	259	---	---	256	
2'' x 0.148'' helically threaded nail	---	---	271	---	244	254	256		---	---	254	---	300	246	267	
2-1/2'' x 0.148'' helically threaded nail	---	---	---	279	273	269	274		---	---	---	294	290	258	281	

2. In comparison with the immediate and five-week delayed withdrawal resistance per inch of penetration of the 2-1/2" x 0.129" (8d) common wire nail, the other nails tested were found to perform as shown below:

Nail Description	Withdrawal Resistance Per Inch of Penetration Immediate	Withdrawal Resistance Per Inch of Penetration Delayed
(a) 10d and 12d Common wire nails with 12% larger shank diameter	113%	96%
(b) barbed nail with 15% larger shank diameter	99%	93%
(c) helically threaded nail with 5% larger shank diameter	126%	233%
(d) helically threaded nail with 15% larger shank diameter	165%	323%

Obviously, the barbs employed reduce the holding power of the nail in both immediate and delayed with-

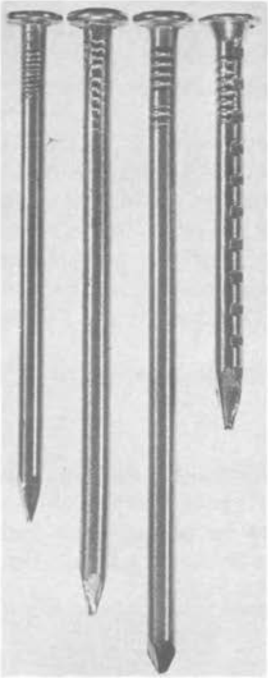

Figure 3. Left to right: 8d -- 2-1/2" x 0.129", 10d -- 3" x 0.145", and 12d -- 3-1/4" x 0.145" common wire nails and 2" x 0.148" superficially barbed nail.

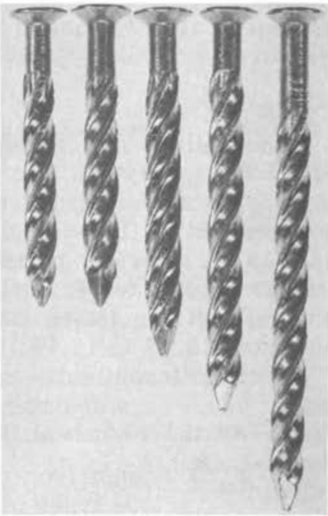

Figure 4. Left to right: 1-1/2" x 0.135" and 1-1/2", 1-3/4", 2" and 2-1/2" x 0.148" bright low-carbon steel, helically threaded nails with 1/4" or 1/2" clearance between head and threads.

TABLE 3 – AVERAGE EFFECTIVENESS, IN POUNDS, OF VARIOUS LOW-CARBON STEEL NAILS IN THE FASTENING OF DOUGLAS FIR PLYWOOD TO AIR-SEASONED DOUGLAS FIR LUMBER

Nail Type	Nail Size	Nail Count	Nail No.	Axial Withdrawal Resistance											
				Immediate (20% M.C.)						Delayed (20%→12% M.C.)					
	Plywood Thickness:			3/8"	1/2"	5/8"	3/4"	7/8"	1"	3/8"	1/2"	5/8"	3/4"	7/8"	1"
	Plywood Edge Distance:														
8d Common	2½" x 0.129"	99	1062	350	292	---	---	---	---	173	173	---	---	---	---
10d "	3 " x 0.145"	62	1063	---	---	481	---	---	---	---	---	230	---	---	---
12d "	3¼" x 0.145"	60	1064	---	---	---	403	334	451	---	---	---	206	181	157
Barbed	2 " x 0.148"	98	982	---	213	---	204	---	158	---	117	---	90	---	84
Hel. thr.	1½" x 0.135"	156	1057	230	189	---	---	---	---	245	175	---	---	---	---
Hel. thr.	1½" x 0.148"	132	1058	---	236	195	---	---	---	---	293	234	---	---	---
Hel. thr.	1¾" x 0.148"	115	1059	---	---	314	242	---	---	---	---	285	259	---	---
Hel. thr.	2 " x 0.148"	102	1060	---	---	373	---	274	254	---	---	349	---	338	246
Hel. thr.	2½" x 0.148"	82	1061	---	---	---	489	444	404	---	---	---	514	471	387

Nail Type	Nail Size	Nail Count	Nail No.	Lateral Load-Carrying Capacity											
				Immediate (16% M.C.)											
	Plywood Thickness:			3/8"		1/2"		5/8"		3/4"		7/8"		1"	
	Plywood Edge Distance:			3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"
8d Common	2½" x 0.129"	99	1062	385	---	430	---	---	---	---	---	---	---	---	---
10d "	3 " x 0.145"	62	1063	---	---	---	---	583	---	---	---	---	---	---	---
12d "	3¼" x 0.145"	60	1064	---	---	---	---	---	---	496	---	759	---	668	---
Barbed	2 " x 0.148"	98	982	---	---	474	---	---	---	441	---	---	---	482	---
Hel. thr.	1½" x 0.135"	156	1057	350	469	425	505	---	---	---	---	---	---	---	---
Hel. thr.	1½" x 0.148"	132	1058	---	---	403	513	479	---	---	---	---	---	---	---
Hel. thr.	1¾" x 0.148"	115	1059	---	---	---	---	508	650	435	587	---	---	---	---
Hel. thr.	2 " x 0.148"	102	1060	---	---	---	---	557	684	---	---	585	747	522	---
Hel. thr.	2½" x 0.148"	82	1061	---	---	---	---	---	---	436	677	643	880	608	822

Nail Type	Nail Size	Nail Count	Nail No.	Lateral Load-Carrying Capacity											
				Delayed (16%→12% M.C.)											
	Plywood Thickness:			3/8"		1/2"		5/8"		3/4"		7/8"		1"	
	Plywood Edge Distance:			3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"
8d Common	2½" x 0.129"	99	1062	327	---	332	---	---	---	---	---	---	---	---	---
10d "	3 " x 0.145"	62	1063	---	---	---	---	480	---	---	---	---	---	---	---
12d "	3¼" x 0.145"	60	1064	---	---	---	---	---	---	463	---	467	---	517	---
Barbed	2 " x 0.148"	98	982	---	---	370	---	---	---	399	---	---	---	442	---
Hel. thr.	1½" x 0.135"	156	1057	336	400	398	502	---	---	---	---	---	---	---	---
Hel. thr.	1½" x 0.148"	132	1058	---	---	398	497	506	---	---	---	---	---	---	---
Hel. thr.	1¾" x 0.148"	115	1059	---	---	---	---	557	643	413	646	---	---	---	---
Hel. thr.	2 " x 0.148"	102	1060	---	---	---	---	550	651	---	---	609	776	558	---
Hel. thr.	2½" x 0.148"	82	1061	---	---	---	---	---	---	422	674	588	819	542	764

Nail Type	Nail Size	Nail Count	Nail No.	Lateral Load Transmission at 0.050" Joint Deformation											
				Immediate (16% M.C.)											
	Plywood Thickness:			3/8"		1/2"		5/8"		3/4"		7/8"		1"	
	Plywood Edge Distance:			3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"
8d Common	2½" x 0.129"	99	1062	185	---	262	---	---	---	---	---	---	---	---	---
10d "	3 " x 0.145"	62	1063	---	---	---	---	284	---	---	---	---	---	---	---
12d "	3¼" x 0.145"	60	1064	---	---	---	---	---	---	320	---	351	---	360	---
Barbed	2 " x 0.148"	98	982	---	---	250	---	---	---	321	---	---	---	377	---
Hel. thr.	1½" x 0.135"	156	1057	197	217	222	240	---	---	---	---	---	---	---	---
Hel. thr.	1½" x 0.148"	132	1058	---	---	229	240	264	---	---	---	---	---	---	---
Hel. thr.	1¾" x 0.148"	115	1059	---	---	---	---	261	247	297	291	---	---	---	---
Hel. thr.	2 " x 0.148"	102	1060	---	---	---	---	303	318	---	---	362	375	341	---
Hel. thr.	2½" x 0.148"	82	1061	---	---	---	---	---	---	320	325	352	358	341	281

Nail Type	Nail Size	Nail Count	Nail No.	Lateral Load Transmission at 0.050" Joint Deformation											
				Delayed (16%→12% M.C.)											
	Plywood Thickness:			3/8"		1/2"		5/8"		3/4"		7/8"		1"	
	Plywood Edge Distance:			3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"	3/8"	5/8"
8d Common	2½" x 0.129"	99	1062	195	---	217	---	---	---	---	---	---	---	---	---
10d "	3 " x 0.145"	62	1063	---	---	---	---	268	---	---	---	---	---	---	---
12d "	3¼" x 0.145"	60	1064	---	---	---	---	---	---	264	---	261	---	288	---
Barbed	2 " x 0.148"	98	982	---	---	208	---	---	---	274	---	---	---	291	---
Hel. thr.	1½" x 0.135"	156	1057	230	170	219	226	---	---	---	---	---	---	---	---
Hel. thr.	1½" x 0.148"	132	1058	---	---	234	218	(240)	---	---	---	---	---	---	---
Hel. thr.	1¾" x 0.148"	115	1059	---	---	---	---	282	280	300	309	---	---	---	---
Hel. thr.	2 " x 0.148"	102	1060	---	---	---	---	314	308	---	---	358	340	330	---
Hel. thr.	2½" x 0.148"	82	1061	---	---	---	---	---	---	(266)	282	309	242	253	222

drawal, while the helical threads, on the average, increase the immediate withdrawal resistance almost 1-1/2 times and the delayed withdrawal resistance almost 2-3/4 times.

3. A comparison of the immediate withdrawal values for nails driven into air-seasoned lumber of 20% moisture content with their delayed test values, obtained after seasoning of the lumber to 12% moisture content (as can be expected during service under conditions commonly prevailing in building construction) indicates the following losses (-) and gains (+) in withdrawal resistance:

Nail Description	In Fastening of Plywood of Given Thicknesses							
	3/8"	1/2"	5/8"	3/4"	7/8"	1"	Avg.	Gr. Avg.
2-1/2" x 0.129" common wire nail	-51%	-41%	----	----	----	----	-46%	-51%
3" x 0.145" common wire nail	----	----	-51%	----	----	----	-52%	
3-1/4" x 0.145" common wire nail	----	----	----	-49%	-46%	-65%	-53%	
2" x 0.148" barbed nail	----	-45%	----	-56%	----	-47%	-49%	-49%
1-1/2" x 0.135" helically threaded nail	+7%	-7%	----	----	----	----	±0%	+5%
1-1/2" x 0.148" helically threaded nail	----	+24%	+20%	----	----	----	+22%	
1-3/4" x 0.148" helically threaded nail	----	----	-9%	+7%	----	----	-1%	
2" x 0.148" helically threaded nail	----	----	-6%	----	+23%	-3%	+5%	
2-1/2" x 0.148" helically threaded nail	----	----	----	+5%	+6%	-4%	+2%	

Thus, the plain-shank and barbed nails can be expected to lose one-half of their initial withdrawal resistance, while the helically threaded nails retain their initial effectiveness or even increase it to as much as 1-1/4 times their initial holding power, even during relatively small reduction in moisture content, due to seasoning subsequent to nailing. Consequently, in evaluating the effectiveness of nails with respect to withdrawal resistance, consideration must be given to the delayed withdrawal resistance of plain-shank and barbed nails under service conditions commonly encountered.

4. In the light of the above findings, and on the basis of the delayed withdrawal values, we find that:

   (a) the 2-1/2" x 0.129" (8d) common wire nail can be replaced by the 1-1/2" x 0.135" helically threaded nail for fastening 3/8" and 1/2" plywood.

   (b) the 3" x 0.145" (10d) common wire nail can be replaced by the 1-1/2" x 0.148" helically threaded nail for fastening 5/8" plywood.

   (c) the 3-1/4" x 0.145" (12d) common wire nail can be replaced by the 1-3/4" x 0.148" helically threaded nail for fastening 3/4" plywood; and by the 2" x 0.148" helically threaded nail for fastening 7/8" and 1" plywood.

B. Lateral Load Transmission at 0.050" Total Joint Deformation

1. Any influence of the edge distance on the lateral load transmission of the helically threaded nails at 0.050" total joint deformation was investigated. In comparison with an edge distance of 3/8", that of 5/8" resulted in the following increases (+) and decreases (-) in test values:

Nail Size	In Fastening of Plywood of Given Thicknesses															
	Immediate								Delayed							
	3/8"	1/2"	5/8"	3/4"	7/8"	1"	Avg.	Gr. Avg.	3/8"	1/2"	5/8"	3/4"	7/8"	1"	Avg.	Gr. Avg.
1-1/2" x 0.135"	+10%	+8%	---	---	---	---	+9%	+9%	-26%	+3%	---	---	---	---	-12%	-12%
1-1/2" x 0.148"	---	+5%	---	---	---	---	+5%	-1%	---	-7%	---	---	---	---	-7%	-7%
1-3/4" x 0.148"	---	---	-5%	-2%	---	---	-4%		---	---	-1%	+3%	---	---	+1%	
2" x 0.148"	---	---	+5%	---	+4%	---	+4%		---	---	-2%	---	-5%	---	-4%	
2-1/2" x 0.148"	---	---	---	+2%	+2%	-18%	-5%		---	---	---	---	-22%	-12%	-17%	
Gr. Avg.								+1%								-8%

An edge distance exceeding 3/8" seems to have no appreciable influence on the lateral load transmission at 0.050" or smaller joint deformation.

2. A comparison of the immediate lateral load transmission at 0.050" joint deformation of nails driven into air-seasoned lumber of 16% moisture content with their delayed lateral load transmission, after seasoning of the lumber at 12% moisture content, indicates the following gains (+) and losses (-) in effectiveness during lumber seasoning:

Nail Description	In Fastening of Plywood of Given Thicknesses							
	3/8"	1/2"	5/8"	3/4"	7/8"	1"	Avg.	Gr. Avg.
2-1/2" x 0.129" common wire nail	+5%	-17%	----	----	----	----	-6%	-14%
3" x 0.145" common wire nail	---	----	-6%	----	----	----	-6%	
3-1/4" x 0.145" common wire nail	---	----	----	-18%	-26%	-20%	-21%	
2" x 0.148" barbed nail	---	-17%	----	-15%	----	-23%	-18%	-18%
1-1/2" x 0.135" helically threaded nail	-2%	-4%	----	----	----	----	-3%	-6%
1-1/2" x 0.148" helically threaded nail	---	-4%	----	----	----	----	-4%	
1-3/4" x 0.148" helically threaded nail	---	----	+10%	+4%	----	----	+7%	
2" x 0.148" helically threaded nail	---	----	+0%	----	-5%	-3%	-3%	
2-1/2" x 0.148" helically threaded nail	---	----	----	-13%	-22%	-24%	-20%	

Thus, the plain-shank and barbed nails can be expected to lose some of their initial load transmission at 0.050" total joint deformation even during the limited seasoning of the nailed lumber from 16 to 12% moisture content. The average loss for the helically threaded nails was found to be considerably smaller and possibly insignificant from the practical viewpoint.

3. In the light of these findings, and on the basis of the delayed test values, we find that:
    (a) the 2-1/2'' x 0.129'' (8d) common wire nail can be replaced by the 1-1/2'' x 0.135'' helically threaded nail for fastening 3/8'' and 1/2'' plywood.
    (b) the 3'' x 0.145'' (10d) common wire nail can be replaced by the 1-3/4 x 0.148'' helically threaded nail for fastening 5/8'' plywood.
    (c) the 3-1/4'' x 0.145'' (12d) common wire nail can be replaced by the 1-3/4'' x 0.148'' helically threaded nail for fastening 3/4'' plywood; and by the 2'' x 0.148'' helically threaded nail for fastening 7/8'' and 1'' plywood.

C. Lateral Load-Carrying Capacity

1. The edge distance, that is, the distance between nail and plywood edge, can be of influence on the ultimate lateral load-carrying capacity of the nails in the fastening of plywood of different thicknesses. In comparison with an edge distance of 3/8'', that of 5/8'' resulted in the following increases in test values for the helically threaded nails:

Nail Size	In Fastening of Plywood of Given Thicknesses															
	Immediate								Delayed							
	3/8''	1/2''	5/8''	3/4''	7/8''	1''	Avg.	Gr. Avg.	3/8''	1/2''	5/8''	3/4''	7/8''	1''	Avg.	Gr. Avg.
1-1/2'' x 0.135''	+34%	+19%	---	---	---	---	+26%	+26%	+19%	+26%	---	---	---	---	+22%	+22%
1-1/2'' x 0.148''	---	+27%	---	---	---	---	+27%	+34%	---	+25%	---	---	---	---	+25%	+35%
1-3/4'' x 0.148''	---	---	+28%	+35%	---	---	+32%		---	---	+15%	+56%	---	---	+36%	
2'' x 0.148''	---	---	+23%	---	+28%	---	+26%		---	---	+18%	---	+27%	---	+22%	
2-1/2'' x 0.148''	---	---	---	+55%	+37%	+35%	+42%		---	---	---	+60%	+39%	+41%	+47%	
Gr. Avg.								+32%								+33%

Therefore, the immediate and delayed basic values for helically threaded nails with an edge distance of 3/8'' can be increased, on the average, 1-1/3 times in the "field" nailing of plywood, and in the "edge" nailing of plywood where an edge distance of 5/8'' or more is available, such as where the plywood crosses the supporting lumber.

2. A comparison of the immediate ultimate load-carrying capacity of nails driven into air-seasoned lumber of

16% moisture content with their delayed lateral load-carrying capacity, after seasoning of the lumber to 12% moisture content indicates the following gains (+) and losses (-) in effectiveness during lumber seasoning:

Nail Description	In Fastening of Plywood of Given Thicknesses							
	3/8''	1/2''	5/8''	3/4''	7/8''	1''	Avg.	Gr. Avg.
2-1/2'' x 0.129'' common wire nail	-15%	-23%	----	----	----	----	-19%	-21%
3'' x 0.145'' common wire nail	----	----	-18%	----	----	----	-18%	
3-1/4'' x 0.145'' common wire nail	----	----	----	-7%	-38%	-23%	-23%	
2'' x 0.148'' barbed nail	----	-22%	----	-10%	----	-40%	-24%	-24%
1-1/2'' x 0.135'' helically threaded nail	-10%	-4%	----	----	----	----	-7%	-1%
1-1/2'' x 0.148'' helically threaded nail	----	-2%	+6%	----	----	----	+2%	
1-3/4'' x 0.148'' helically threaded nail	----	----	+4%	+2%	----	----	+3%	
2'' x 0.148'' helically threaded nail	----	----	-3%	----	+4%	+7%	+3%	
2-1/2'' x 0.148'' helically threaded nail	----	----	----	-2%	-8%	-9%	-6%	

Thus, the plain-shank and barbed nails can be expected to lose, even during relatively limited seasoning of the lumber, almost one-quarter of their initial ultimate lateral load-carrying capacity, while the helically threaded nails retain their initial effectiveness. Therefore, in evaluating the effectiveness of nails with regard to lateral load-carrying capacity, consideration should be given to the reduced, delayed lateral load-carrying capacity of plain-shank and barbed nails, even after slight reductions in moisture content subsequent to nailing.

3. In the light of these findings, and on the basis of the delayed test values, we find that:

   (a) the 2-1/2'' x 0.129'' (8d) common wire nail can be replaced by the 1-1/2'' x 0.135'' helically threaded nail for fastening 3/8'' or 1/2'' plywood.

   (b) the 3'' x 0.145'' (10d) common wire nail can be replaced by the 1-1/2'' x 0.148'' helically threaded nail for fastening 5/8'' plywood.

   (c) the 3-1/4'' x 0.145'' (12d) common wire nail can be replaced by the 2'' x 0.148'' helically threaded nail for fastening 3/4'', 7/8'', or 1'' plywood. (The 1-3/4'' x 0.148'' helically threaded nail provides 11% smaller delayed lateral load-carrying capacity than the 12d common wire nail in fastening 3/4'' plywood.)

SUMMARY

Conventional nailing of plywood panels cannot take full advantage of the design strength of plywood, principally because of the limitations of common wire nails. The stout, that is, relatively short, large-diameter, properly threaded nails of similar or lighter weight than corresponding common wire nails can fasten plywood sheathing in a far more effective and efficient manner than is possible with common wire nails of recommended size. Effective resistance to immediate and delayed withdrawal is especially important where, for instance, plywood buckling, wind suction, and uplift due to wind forces may enter the picture. The considerably greater withdrawal resistance of properly threaded nails, compared to plain-shank nails, can have a definite influence on the strength, as well as the life, of the structure. The greater effectiveness of these improved nails also facilitates straightening of warped lumber, by pulling the members together during nailing, and tying down flat plywood when forming curved shapes, as is the case in the framing of plywood arches and shell structures.

These improved nails are as effective, and can be more efficient, in transmitting shear loads than common wire nails. This is especially important, for instance, in the fastening of plywood for diaphragm panels designed to resist racking forces and such shear forces as are encountered in shell structures, folded plates, hyperbolic and other paraboloids.

It is common knowledge, and reconfirmed by the tests described, that plain-shank nails and superficially barbed nails lose a considerable amount of their initial withdrawal resistance during seasoning of green-nailed lumber. Few people realize that such loss in withdrawal resistance is also encountered during supplementary seasoning of lumber which was nailed even after seasoning far below the fiber-saturation point of the wood. Only a few people are aware of the fact, again demonstrated by these tests, that the lateral load transmission of the nailed joint at small deformation and the ultimate lateral load-carrying capacity of these plain-shank and barbed nails are adversely influenced by wood shrinkage during seasoning of the nailed lumber, even if it was nailed after seasoning to as low a moisture content as 16% and dried after nailing to 12%. On the other hand, it has been proven again and again, and reconfirmed by these test data that properly threaded nails retain or even increase their effectiveness in resistance to withdrawal and transmission of lateral loads while the nailed lumber seasons from green or partially seasoned condition. These significant reductions in effectiveness of plain-shank and superficially barbed nails are of particular importance in any decision to select properly threaded nails for diaphragm construction, as well as for all-nailed trussed rafters. These are just a few of the assemblies where the permanently satisfactory withdrawal and shear resistance of properly threaded nails can be one of the reasons for the justifiably long life expectancy of the structure involved.

It is also important to note that, since the improved nails are threaded, they can be shorter than plain-shank nails. Their short length makes them less likely than common wire nails to protrude or pop during seasoning of lumber which was nailed when green or only partially seasoned. In addition, if properly designed, the threads themselves provide considerable resistance to nail protrusion and popping. Consequently, these improved nails can fasten sheathing far more rigidly than plain-shank nails, especially under adverse service conditions.

Being shorter than the common wire nails generally used for fastening plywood sheathing, the stout nails are handled easier. Being short and relatively large in diameter, they are less likely to bend during driving and thus can be driven harder and faster.

In light of these facts, it appears justified from the technical, economic, and practical viewpoints to replace common wire nails with the stout, threaded nails for fastening plywood sheathing in an effort to build better, stronger and longer lasting structures at less initial cost, as well as lower maintenance cost.

Criteria for the selection of nails in the fastening of plywood must be based on their immediate and delayed axial withdrawal resistance, their lateral load transmission at small joint deformation, and their ultimate lateral load-carrying capacity. From the information presented, it is possible to determine which stout, helically threaded nail provides at least equivalent or considerably better performance than the common wire nail presently required for fastening of 3/8'', 1/2'', 5/8'', 3/4'', 7/8'', and 1'' plywood. Such a desirable replacement of common wire nails is indicated in the following tabulation:

Common Wire Nail	Governing Loading Condition	Helically Threaded Nails in Fastening of Plywood of Given Thicknesses					
		3/8''	1/2''	5/8''	3/4''	7/8''	1''
8d--2-1/2'' x 0.129''	Ultimate Withdrawal	1-1/2'' x 0.135''	1-1/2'' x 0.135''	-----	-----	-----	-----
	Lateral at Small Deform.	1-1/2'' x 0.135''	1-1/2'' x 0.135''	-----	-----	-----	-----
	Ultimate Lateral	1-1/2'' x 0.135''	1-1/2'' x 0.135''	-----	-----	-----	-----
10d--3'' x 0.145''	Ultimate Withdrawal	-----	-----	1-1/2'' x 0.148''	-----	-----	-----
	Lateral at Small Deform.	-----	-----	1-3/4'' x 0.148''	-----	-----	-----
	Ultimate Lateral	-----	-----	1-1/2'' x 0.148''	-----	-----	-----
12d--3-1/4'' x 0.145''	Ultimate Withdrawal	-----	-----	-----	1-3/4'' x 0.148''	2'' x 0.148''	2'' x 0.148''
	Lateral at Small Deform.	-----	-----	-----	1-3/4'' x 0.148''	2'' x 0.148''	2'' x 0.148''
	Ultimate Lateral	-----	-----	-----	2'' x 0.148''	2'' x 0.148''	2'' x 0.148''

The suggested replacement of common wire nails with stout, helically threaded nails should result in permanently effective joints. The use of longer, improved nails than those listed for general use is, of course, advisable under conditions requiring even stronger fastening.

SELECTED REFERENCES

1. American Society of Civil Engineers. "Load test of a diagonally sheathed timber building," Journal of the Structural Division,

American Society of Civil Engineers, Vol. 82, No. 972, pp. 59-60, May 1956. Also reported in: American Society for Testing and Materials. Symposia on Design and Tests of Building Structures, Seismic and Shock Loading, Glued Laminated and Other Constructions. Special Technical Publication No. 209, p. 32, Philadelphia, Pa.: the Society, 1957.

2. American Society of Mechanical Engineers. "Improved nails," ASME Transactions, Vol. 72: No. 7, pp. 987-988, October 1950.
3. Douglas Fir Plywood Association. Basic Facts About Fir Plywood Diaphragms. Form No. 57-220. Tacoma, Wash.: the Association, 1957.
4. Practical Builder. "Home of the year," Vol. 22: No. 8, pp. 92-105, July 1957. Also see: Building Research Institute. "Neoprene as a roof coating," Plastics in Roof Construction, pp. 56-61. Washington, D. C.: the Institute, 1957; and National Association of Home Builders Research Institute. NAHB Research House. Washington, D. C.: the Association, 1958.
5. U. S. Department of Agriculture. Wood Handbook. Washington, D. C.: U. S. Government Printing Office, 1955.
6. Virginia Polytechnic Institute Wood Research Laboratory. Wood, Plywood or Steel Gusset Plates for Nailed Trussed Rafters. Bulletin No. 29. Blacksburg, Va.: the Institute, 1957. Also: VPI Wood Research Laboratory. Fastening of Truss Plates with Screwtite "Hi-Load" Nails. Bulletin No. 43. Blacksburg, Va.: the Institute, 1961.
7. Virginia Polytechnic Institute Wood Research Laboratory. Effectiveness of Boat Nails. Bulletin No. 22. Blacksburg, Va.: the Institute, 1956.
8. Virginia Polytechnic Institute Wood Research Laboratory. Nailing of Plywood Sheathing with "Hi-Load" Nails. Bulletin No. 35. Blacksburg, Va.: the Institute, 1958.
9. Virginia Polytechnic Institute. Wood Research Laboratory. Fastening of Plywood with Screwtite "Hi-Load" Nails. Bulletin No. 44. Blacksburg, Va.: the Institute, 1961.

Application of Screw Fasteners to Wood Construction

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Abstract: Typical applications for the use of screw fasteners in wood construction are discussed, noting when screw-type fasteners should be substituted for nails. Advantages of using the type A sheet metal screw thread fastener are discussed, followed by a listing of the factors to consider in selection of wood screws, lag-type screws, and type A sheet metal fasteners. Proper installation procedures are outlined. The importance of using pilot holes in certain materials is stressed, and mention is made of bolt and screw fasteners for wood structural applications and for anchoring heavy objects.

IN MAN'S INCREASINGLY FRANTIC SCRAMBLE for more rapid progress, he leaves many products and concepts behind, tagged as "obsolete." For the sake of progress, this is, of course, fortunate in the broad sense of the word. Unfortunately, however, we also tend to leave many constructive ideas and products in the so-called obsolete trash pile and to overlook many physically small but potentially good items.

A good example of an item, infinitesimal compared to missiles or atomic reactors, small compared to the advanced architectural structures designed today, is the fastening device.

When improved techniques for manufacturing nails made it possible to produce inexpensive fastening devices, man's natural tendency was to make them a cure-all for fastening in all sorts of wood construction. Too often overlooked in the scramble has been the screw type of fastening; this, despite the fact that the screw is one of man's oldest and most time-tested devices to obtain leverage, and hence, strong fastening. An example of the tremendous leverage obtainable through screw thread devices is the jacks which are used to lift entire buildings off their foundations. Yet, the screw fastener is often overlooked in applications where it could do a job superior to many of the so-called "progressive devices."

DEVELOPMENT OF WOOD FASTENERS

Let's quickly scan progress in fastening wood in this country, and perhaps we can gain a little better insight into the whys and

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wherefores of recent developments. From early American history, we know that until the wood screw became practical, wooden pegs, wires, etc., were used to fasten wood to wood and other appurtenances to wood. Nails were available, but they were very rough in form and also scarce.

The wood screw represented a fantastic advance in technique for fastening to wood. The first ones, as we know, were practically handmade and, like the early nail, were precious to come by. Gradually the wood screw became refined to the point where automatic machining devices turned out millions of these fasteners and made broader use of them economically feasible.

All during this time, the nail fastening device was undergoing improvement both as to manufacturing techniques and style. An improvement that made use of the nail more feasible was development from a hot-made, hand-made device into a cold-forged, rapidly produced item with nail points and heads actually formed cold from wire.

Prior to World War II, it made very little difference to most people whether a screw or a nail was used in wood construction. Usually, the decision was based largely on the actual cost of the material itself. Whether the nails or the screws were cheaper to use was the deciding factor. Those were the days when material costs represented the larger part of the total cost.

But, during the war and particularly from the post-war period up to the present, labor costs have spiraled to the extent that labor, installation, and maintenance have become, by far, the largest part of total costs. This, of course, has cast an entirely new light on decisions affecting fastening devices in wood construction. In constant attempts to keep up with the rising costs of building construction, many methods have been devised to keep the total costs of structures down. In terms of fastening to wood, major efforts tended in the direction of designing and producing better nails. Since it was known that screw threads had certain advantages for wood construction, adaptations of screw threads were designed into nails. Cement-coated, annularly threaded, barbed, and other types of nails became commonplace.

Techniques were developed for producing wood screws faster and faster, so that their costs became reduced in the general market place. For a few years directly after World War II, wood screws were one of the cheapest methods of fastening to wood because of this increased production rate. As we shall see, other developments also enhanced the value of wood screws in construction. One significant change was the increased use of the type A sheet metal screw thread fastener for fastening to wood. This began primarily as a substitution for wood screws at such times as wood screws were not quickly available or in occasional cases of price advantage. In some instances, lag screws were also substituted for wood screws for similar reasons.

TYPICAL APPLICATIONS

Time does not permit us to examine in detail the countless applications where screw fastenings are used in wood construction, but we can examine some of the more typical applications and attempt an evaluation of such usage. Typical applications are:

1. Attaching industrial building skins to wood framework
2. Attaching hardware to wood in all types of building construction
3. Attaching wood to wood, as in residential frame construction
4. Attaching shingles of various compositions to residential wooden framing.

Nail Fasteners

To relate the more popular fastening devices to these typical building construction applications, some important considerations pertaining to nail fasteners are:

1. Since most structures are exposed to the effects of expansion, contraction, freezing and thawing, various amounts of stress, shear and tensile strength are involved. Where these factors are of serious dimension, it can be said that nails are not typically designed to carry these loads adequately. Shearing and nail pop-out are the usual problems under these conditions.
2. Installation of nails is probably faster than any other device for fastening to wood. On the other hand, there is a constant risk of damage to the surface of the material being fastened. A hammer blow, carrying impact strength to as much as a ton per blow, tends to crack or go right through metallic or other surfaces, if they are not unusually strong or thick. However, some designs of nails offer larger bearing surfaces to help protect the material being fastened from damage. Many types of nails are also subject to bending if driven into dense woods, causing inconvenient and costly delays.
3. Nails designed with bearing washers assembled, or heads and laminated sealing devices as an integral part of the fastener, represent an advance in the prevention of excessive costs due to leakage.
4. The extent of bearing area and sealing washer is important, since a hammer blow through a surface means that any insulation from the elements is removed, neutralizing the effect of the sealing material.

5. With our increasing concern with the aesthetics of appearance, it should be remembered also that hammer blows damaging hardware, surface skins, siding or other coverings definitely have a marring effect. Such damage can lead to rapid corrosive deterioration, which also affects appearance.

6. Since the bearing or holding strength of the typical nail fastener is substantially less than that of screw fasteners, as indicated by tests, maintenance and structural integrity must be considered. Even the screw shank type of nail, which represents an attempt to add some of the holding power of a true screw thread, cannot compare with it in strength, since its helical angles must tend toward the vertical, consequently reducing holding power (see Figure 1). This is a particularly important consideration in securing roofing and siding to industrial, commercial, and residential structures.

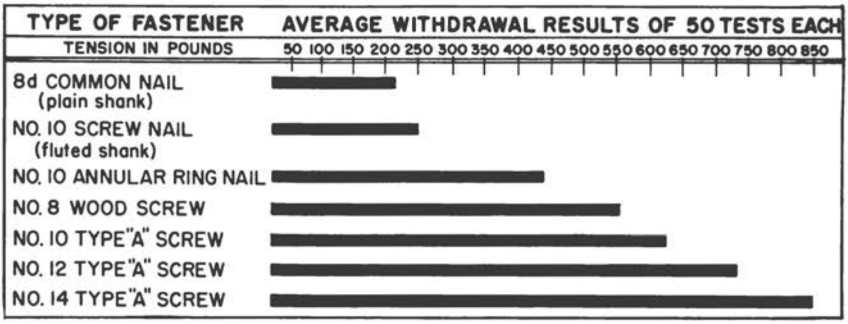

Figure 1 -- Comparative immediate withdrawal results from tests of fasteners driven into yellow pine to one-inch penetration and pulled immediately.

7. In attaching hardware to wood, one of the important considerations typically prohibiting the use of nails is the damage to the hardware itself from the hammer striking it.

8. In residential wooden framing, nailing wood to wood, there seems to be no particular reason to deviate from common nails. This is, of course, true so long as residential framing remains traditional in design. Nails can be applied fast, in this instance, and hammer blows do not substantially weaken the framework. Also, since the actual strength of the framing lies in the opposition of the members themselves, it would seem unnecessary to consider any other device than nails in this conventional construction.

9. One of the fields long neglected, and certainly overlooked as a field for progress in screw fastening, is that of residential shingles. The effects of storms, high winds, rains and rust-

ing are well known by all. The cost of damage by hammering nails into certain types of shingles must be substantial. Insurance rates reflect the constant damage occurring because nail devices have not been able to hold shingles down consistently under the effects of storms, freezing and thawing, and the elements in general. Some improvements have been made through the use of nails with spiral shanks and non-load-bearing neoprene washers, but these have not proven generally satisfactory under these severe conditions.

A study made by engineers at Purdue University of 2,000 roofing installations specifically concluded that "fasteners and weathering are highly significant factors in contributing to damaged sheet metal roofing." In all cases, the fasteners were nails. In the case of shingle roofs, the study attributed leakage and failures to wind and insufficient design and holding power of nails. This report, published in the September 1955 issue of Roofing, Siding, and Insulation magazine (3), covered both farm and residential roofing and provided significant evidence of the over-all advantage of using screw fastenings in such applications.

Screw Fasteners

Some of the economics of using a drive type of fastener cannot be argued, but as we examine the other methods of fastening in wood construction, some interesting conclusions can be drawn. Some of the considerations in the use of wood screws in such applications are:

1. Wood screws, having a more horizontal screw type thread, have more holding power than nail devices. Therefore, they represent stronger fastenings for most wood applications.
2. The wood screw generally has widely spaced threads, which are limited in depth because of the tapered type of shank, and the strength values are in relation to depth of threads cut into the shank. The wood screw, in other words, does not represent maximum holding power.
3. Since conventional wood screw threads must be cut, shear planes are exposed and, generally, wood screws have more limited shear and tensile strength than cold-formed threads. These are usually not significant in applications such as attaching hardware or fastening non-load-bearing joints.
4. Varieties of wood screws are available which do have more holding power, and can be more rapidly installed than the cut thread style. These have a rolled type of thread, usually of twin thread design, and they offer a certain economic advantage as well as increased holding power. Installation of wood screw fasteners in wood construction is, of course,

slower than nails. This is true not only because it is necessary to rotate the screw in driving but, to be assured of a proper joint, pilot holes should be used.

5. On the other hand, there is far less danger of splitting wood fibers or doing other costly damage of this nature if the wood screw is properly applied than would be the case with nail type fasteners.

An increasingly common screw type of fastener used in the applications indicated above is the type A sheet metal screw thread fastener. The reasons for this, and some of the considerations, are:

1. The type A screw, since its threads are more closely spaced and deeper than the standard-cut thread wood screw or nail, usually offers more holding power than either (see Figure 2).

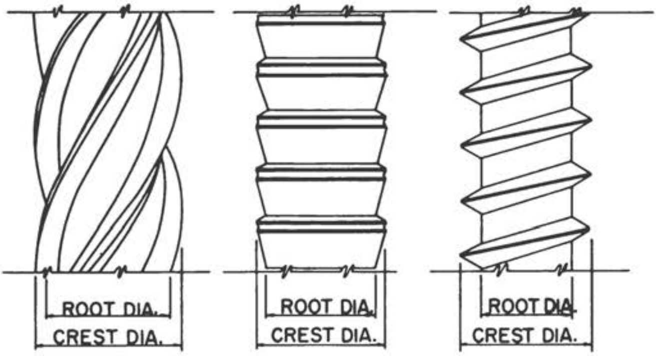

Figure 2 -- Thread comparison of threaded and screw-type nails with that of screws. Left to right: screw-type nail, annularly threaded nail, wood screw.

2. Type A thread screw devices are available equally as readily as the wood screws and nails discussed previously.
3. Many designs of type A fasteners are equipped with sealing washer devices assembled as an integral part of the fastener to provide weathertight joints. This development has come about since World War II, and helps overcome the objection to fasteners as a potential cause of leakage in buildings.
4. The type A thread fastener is also slower to install than a nail. Again, this is because the fastener must be rotated, and to obtain truly proper holding power, pilot holes should be drilled in most applications. If correctly engineered, one type A screw fastening can replace up to four nail fasteners of any design in an application. This should be a consideration in the over-all economics and performance potential represented by screw fastening devices.

5. Installed in pilot holes of proper size, there is actually less danger of splitting wood in typical applications than there is with a nail type of fastener which depends on impact and penetration through the solid substance. Perhaps their small contribution to reduction of insurance rates might be another economic factor in favor of screw fastening devices for at least several of the applications we are discussing. Aftermaths of the hurricanes, tornadoes, cyclonic storms, and heavy thunderstorms cost the American public untold millions of dollars in increased insurance premiums over a long term. Perhaps the screw fastener, in its own tiny way, can assist in keeping insurance rates down, since holding power means less damage during storms.
6. In view of the foregoing considerations and many more too numerous to mention here, it might be said that a type A screw fastening device is definitely the best current answer for attaching skins to buildings, and shingles of various types to residential roofing and siding, and is equally as good as a wood screw for attaching hardware to wooden members or surfaces. We can also conclude that this type of device is not really needed for the traditional wood structural framing of small buildings such as residences. As is true in the use of any material or component, selection of proper styles of screw fasteners and use of correct installation procedure to match the selection are extremely important to obtain maximum performance benefits.

SELECTION OF SCREW FASTENERS

Generally speaking, factors to consider in the selection of styles of wood screws, lag-type screws, and type A sheet metal screw thread fasteners follow a similar pattern. I would like to review a few of the more popular styles and discuss them pro and con.

1. SLOTTED HEADS -- The slotted, round, truss, hex, or other style of head has decreased in popularity in recent years because of the problem of screwdriver bits slipping from the slots at a certain torque level. In applications where this is desirable, the slotted head offers an easy answer. In the consumer, do-it-yourself, wood construction market, the slotted head is still popular because the average household has a straight bit screwdriver, if nothing else.
2. PHILLIPS RECESS HEADS -- Phillips recess heads have become increasingly popular since World War I for all kinds of uses. They offer various profile heads with a positive four-corner drive which prevents the slippage which can occur in slotted type heads. In building construction, their

only drawback is that in the outdoor exposure sediment and other corrosive elements can accumulate in the Phillips recess. Several other styles of recess, all intending to accomplish positive drive, are also available for these applications.

3. HEX HEAD -- The hex head is a six-sided head offering a positive driving feature. Available in many variations, it offers advantages both in driving and in appearance. There are trimmed heads for sharp corners, and cold upset heads with slightly chamfered corners. In any application requiring a screw to form its own threads in dense materials, the hex head has proven to be the most effective style of fastener. In materials which are thin and less dense, where strippage of the material itself is a possibility, the hex head must be used with more care.

All of these heads are available with sealing washers as part of the fastening itself. Such sealing elements as molded neoprene washers, plastic materials, bonded neoprene and metal washers, and many others are available already assembled with the screw fasteners. An important consideration when using a screw fastener with an assembled sealing washer for wood is that the fastener has a positive method of retaining the sealing material in the area requiring sealing, under the head or metal washer.

Another important consideration is bearing area. In thin coverings, a larger bearing area is needed to prevent pushing the fastening through material. In cases where strong lateral forces will be exerted against the fastener head, larger and thicker laminated or integral washers are needed.

Where a good appearance is urgent, a screw fastening should have a method of hiding or trapping the sealing material. This is important where there is a potential problem of leakage from the weather elements, such as in industrial building skins, residential shingling or siding, and other exposed applications.

Lag screw devices are usually used for heavier anchoring of materials to wooden framework or back-up members.

The length of a screw device is determined by the amount of load which will be carried by the anchoring or tapping fastener, plus the thickness of the member to which it is being attached. In general, it is desirable to have at least 1 inch to 1-1/2 inches of the full-threaded portion of the fastener penetrating the wooden member behind the material being attached or fastened. In attachment of the typical hardware device in residences and commercial buildings, this penetration is unnecessary, and suggested lengths are usually available from hardware manufacturers.

Fastener Material

In selecting screw fasteners for wood construction, one should consider the material of the fastener itself. Typically, screw fasteners are available in various alloys of stainless, carbon steel, aluminum, brass, and a nickel alloy of copper, iron, and manganese. Ordinarily, either #18-8 stainless alloy or aluminum will provide sufficient corrosion resistance for almost any condition. The 400 series stainless and carbon steels can be used safely in conditions where corrosion is not a serious problem.

Insofar as expense is concerned, obviously the nickel alloy tops the list; whereas the carbon steel is usually cheapest. In the use of aluminum screw fasteners, density of wood and torque should definitely be considered. A non-heat-treated aluminum screw can be twisted off if driven into dense materials or in wrong size pilot holes or without pilot holes. Various heat treatments are available to strengthen the aluminum screw fastener, but the manufacturer should be consulted for recommendations regarding material.

Fastener Installation

Careful consideration of the screw fastening should be augmented by the use of proper installation procedures, or the benefits of correct selection are lost. Almost every screw fastening application requires a pilot hole drilled prior to inserting of the screw. There are many reasons for this, but the two most important ones are that, without pilot holes, the wood fiber or structure itself can be crushed, split, or otherwise damaged. In attempting to drive a screw fastening into a flat surface without pilot hole, it is easy to start the device in crooked, and the cocked or canted screws ultimately result in an unsatisfactory joint.

Correct drill sizes are an important part of the installation procedure. Charts with recommended pilot hole sizes are availalbe from manufacturers of screw fasteners, although unusual conditions may dictate variation from such charts. It is recommended that the manufacturer of screw fasteners, as a specialist in building construction fastening problems, be consulted when there is any doubt.

Screw devices can either be driven with adjustable clutch driving guns and seated accordingly at the proper seating torque, or by the operator's touch. The surface material usually determines the proper torque, and can be ascertained readily from the fastening source. In any event, it can be said that most screw type fastening applications require seating of the fasteners snugly against the surface. One exception is when an assembled hardened metal washer makes it possible to drive fasteners far beyond the limitation of being snug, without "feel" on the part of the applicator.

In light density woods, or woodlike materials, slotted screws often offer an advantage, since the bit of the screwdriver will tend to come out of the slot upon proper snug seating. In the heavier density woods and wood materials, the hex head and various other styles offer the necessary driving leverage to compensate for the heavier driving or torques required, and there is little chance of strippage without excessive carelessness.

OTHER SCREW-TYPE FASTENERS

There are many other screw-type fastenings which are often broadly classified as screws. Time prohibits discussion in detail of this class, called the "bolt and screw line," often lumped together with screw fasteners of the type we have been discussing. The reason for this classification is that the bolt has threads which are screwed into a nut, or vice versa.

In this classification fall such devices as cap screws, machine bolts, fin head bolts, carriage bolts, ribbed bolts, lock bolts, and many other styles. Typically, these bolts serve two functions:

1. The shoulder or fin function is to prevent turning of the bolt while the nut is being tightened on the bolt, or the reverse.
2. A nut is screwed on the shank of the bolt to lock or tighten two materials together.

The bolt and nut class of fasteners is used mostly for wood structural applications such as bolting together heavy beams or parts which are going to be under heavy stress. They are also used for anchoring heavy objects, or objects which are going to be subjected to severe vibration or stress. Bolts and nuts of various types provide the greatest shear and tensile strength, as a rule. They are most vibration-proof when used with a self-locking type of nut. Since they are usually more expensive to apply, both as to material cost and labor cost, they ordinarily are not used for any but the above applications.

The so-called flaring fasteners although not actually screw types, are often confused with them. Actually, the principle behind the flare type of fastener is that the tenon of the shank of the fastener is flared or bulbed mechanically into or behind the wood itself. Examples of this type of fastener would be the mechanical blind rivets or pin drive types of blind fasteners. Since they are installed from one side of the work, they are usually used for attachments to flat surfaces or in attaching strips and other decorative items.

The pull-type mechanical blind rivets exert no force against the outer surface; therefore, they can be used with almost any material, whereas the drive types expose the surface to the driving blow of the hammer or other impact device. Hole size and drilling techniques are more important with these than with screw type fasteners.

A NEW LOOK AT OLD METHODS

The purpose of this paper is to stimulate a new look at screw fastening in wood construction. We hope the review of known performance facts and the proper use of typical screw devices has generated a new curiosity as to what may be done to improve existing "standard" applications. Perhaps a new look at some of these old application methods will suggest over-all economies and stimulate progress toward better performance, as well as applications heretofore not seriously considered for screw fastening techniques. In other words, we suggest a new look at how better use can be made of the old but proven method of screw fastening in wood.

SELECTED REFERENCES

1. American Society of Agricultural Engineers. "Wind loads on farm buildings," ASAE Transactions, January 1912, pp. 22-24.
2. Iowa State College of Agriculture and Mechanical Arts. The Effectiveness of Roofing Nails for Application of Metal Building Sheets. Research Bulletin 355.
3. Roofing, Siding, and Insulation. "Wind proves chief cause of roof failures," September 1955, pp. 12-14.
4. United States Department of Agriculture. Nail-Withdrawal Resistance of American Woods. Bulletin No. 236. Washington, D. C.: U. S. Government Printing Office, 1958.
5. Virginia Polytechnic Institute Wood Research Laboratory. Wood Screws for Building Construction and Wood Products Assembly. Bulletin No. 39. Blacksburg, Va.: the Institute, May 1959.
6. Virginia Polytechnic Institute Wood Research Laboratory. Plain Shank vs. Fluted vs. Threaded Nails. Bulletin No. 27. Blacksburg, Va.: the Institute, December 1956.

Lateral Loading Evaluation of Staples and T-Nails

By R. S. Kurtenacker, U.S. Forest Products Laboratory

Abstract: This paper reports on an investigation by the U.S. Forest Products Laboratory of the performance of pneumatically driven staples and T-nails as compared to conventional nails when subjected to impact and static loading in four different simulated container applications. A capacitance-type load cell, coupled with other electronic instrumentation, and a special process camera were used to obtain and record maximum loads and time durations created by impact. An analysis of the variance in results is presented. Conclusions indicate that certain staples and T-nails may be substituted for conventional nails to fasten 1/4-inch plywood to nominal 1-inch thick cleat stock.

RECENTLY, CONSIDERABLE INTEREST has been shown by the packaging industry, as well as others who use mechanical fasteners for wood, in the possible use and application of relatively lightweight, portable, pneumatically operated tools capable of driving staples and T-nails. Since these tools permit rapid application of fasteners, consideration has been given to their utility for many operations. These uses vary from assembly of components in building construction to the assembly of containers. These tools offer possibilities as labor-saving and time-saving devices in the fabrication of crate panels or large size cleated-panel boxes, as well as for attaching sheathing or panel material to studs and underlayment to joists.

The evaluation discussed here is specifically designed around container or packaging applications, rather than around operations in the building industry. Emphasis is on dynamic data, which are of vital concern to those involved in the design and construction of crates or shipping containers. Naturally, such shock or impact loading is not necessarily of paramount interest to the building industry. Likewise, the use of a clinched nail or fastener is seldom encountered in house construction, but is a technique that is used wherever possible in container construction. Despite this primary emphasis on container application, it seems probable that the data may have at least general interest to those concerned with building construction.

KURTENACKER, R. S. Engineer, U.S. Forest Products Laboratory, U.S. Forest Service, U.S. Department of Agriculture; member, American Society for Testing and Materials.

The U. S. Forest Products Laboratory previously had investigated the use of staples for fastening 3/24-inch-thick plywood to cleats as well as for fastening solid fiberboard to cleats in cleated-panel boxes. This work involved a study of the lateral resistance of staples under slowly applied, or static, load in a universal-type testing machine. In general, the results were substantiated by the performance of cleated-panel boxes in drop-cornerwise tests. Later, exploratory work involving thicker material, such as is generally used in crates, indicated that the lateral static resistance values might be misleading; namely, that the lateral resistance values for staples were somewhat better than for conventional nails, but that drop tests of stapled crates indicated more fasteners were required to approach the performance of a nailed crate.

From this, it appeared necessary to study the behavior of fasteners under impact loading, since impact data might more closely parallel the rough handling of a crate than do the results from static loading. This appears reasonable, since few if any wood containers exhibit fastener failures while the container is at rest or in storage. Almost all of the damage occurs while the container is in motion, and thus is subjected to dynamic loads. There are, no doubt, many methods and techniques for making lateral impact tests of container fasteners, but information on such methods is meager. The work described here is an attempt to explore some of the facets of the lateral impact resistance of container fasteners. Toward this end, the lateral impact resistance of staples and T-nails was investigated and compared with conventional nails at the U.S. Forest Products Laboratory.

The specimens were subjected to lateral impact loads on the FPL toughness machine. Maximum loads were recorded by the use of a load cell and electronic instrumentation that produced a visible trace on an oscilloscope. This trace was photographed with a special process camera.

In conjunction with these impact studies, a limited number of lateral static resistance studies were made to determine whether or not a relationship exists between the dynamic and static results.

DESCRIPTION OF MATERIALS

There are many combinations of wood member sizes with which mechanical fasteners are used. It was not feasible to consider all possible combinations, so four were selected as being generally representative of commonly encountered container applications:

Combination I: Container-grade plywood, 1/4'' thick, fastened flatwise to nominal 1'' (25/32'' thick) cleat material.

Combination II: Nominal 1'' (25/32'' thick) material fastened flatwise to nominal 1'' (25/32'' thick) material.

Combination III: Container-grade plywood, 1/4'' thick, fastened flatwise to nominal 2'' (1-5/8'' thick) cleat material.

Combination IV: Nominal 1'' (25/32'' thick) material fastened flatwise to nominal 2'' (1-5/8'' thick) material.

Wood for the specimens consisted of three-ply container-grade plywood made from group III woods of nominal 1 inch white pine, and of nominal 2 inch southern yellow pine.

After a sufficient number of pieces were cut, each piece was marked, and the two pieces used to make up a specimen were selected by a method of randomization. In any lot or combination of variables, there were 10 replicates for the impact studies and five replicates for those in lateral static resistance.

Each specimen consisted of two pieces arranged in the form of a letter T and fastened together with a single fastener. The stem of the T was 8 inches long by 2-1/4 inches wide and was fastened to a cross-member 6 inches long by 2-1/4 inches wide. The fastener was located at the center of the intersection of the stem and cross-member. Each stem had a 25/32 inch diameter hole whose center was located 1-3/4 inches from the end furthest from the cross-member and at the midpoint of the width. Figure 1 shows an assembled specimen and representative samples of staples and T-nails.

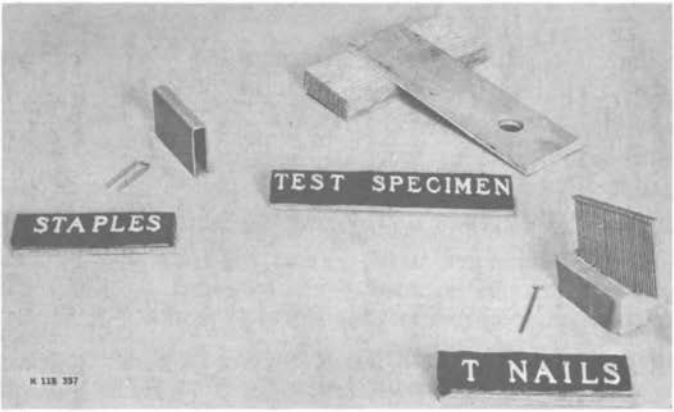

Figure 1 -- Representative staples and T-nails, and assembled specimens used in evaluation of fasteners.

EQUIPMENT

Impact Loading

The equipment and setup for the impact loading studies (Figure 2) consists of a capacitance-type load cell, an oscillator, a discriminator and amplifier, a cathode ray oscilloscope equipped with a special process camera, a photoelectric cell and light source, and the FPL toughness testing machine (2).

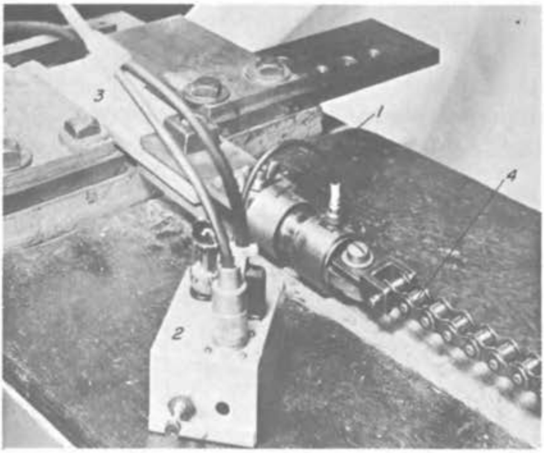

Figure 2 -- Closeup of load cell (1) oscillator (2) and specimen (3) in position for lateral impact load to be applied through chain (4).

The capacitance-type load cell (Figure 3) was connected through a short coaxial cable in such a way that a change in the capacitance of the load cell would change the frequency of the oscillator. The output of the oscillator was fed through a discriminator-amplifier circuit to the cathode ray oscilloscope, so that within the limits of linearity, the impact load creates a strain in the load cell, which alters the capacity and changes the frequency of the oscillator. This varies the direct current voltage output, which produces deflection of the cathode ray beam of the oscilloscope. The deflection of this beam as it moves horizontally across the scope creates a trace of the impact pulse. Since the horizontal displacement was a linear function of time, the resultant trace is a load-time pulse. To fix the duration of loading, timing pulses were impressed on the scope.

Calibration of the load cell and the instrumentation setup was accomplished by placing the load cell in a universal testing machine and applying a known load in increments of 50 pounds.

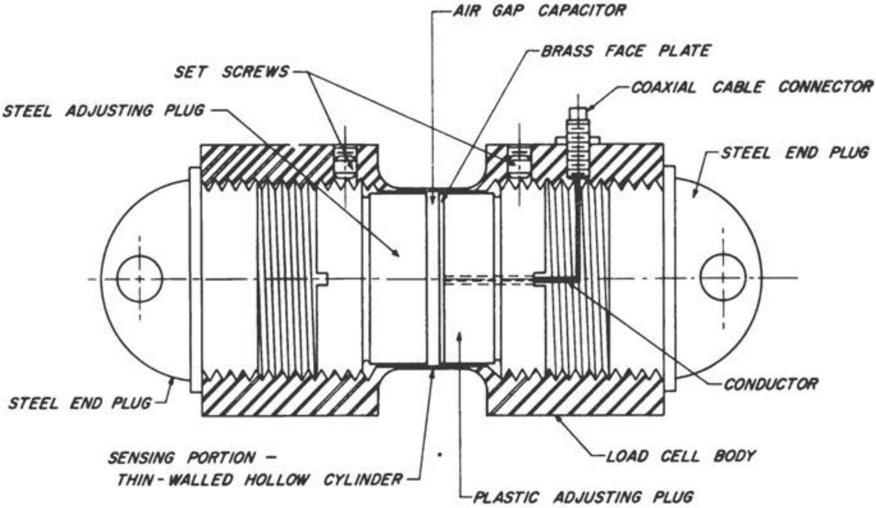

Figure 3 -- Sketch of load cell assembly.

The toughness machine permits a measured amount of energy from the fall of the pendulum to be applied to the specimen. The angles through which the pendulum swings may be read from a stationary graduated scale and a vernier operated by the drum.

Static Loading

The static loading studies were conducted on a universal testing machine operating at a head speed of 0.25 inch per minute. The machine was equipped with a recording device and ink pen arrangement so as to obtain a graph of the load deformation for each specimen.

METHOD OF LOADING

All wood pieces for the specimens were placed in a controlled atmosphere of 75° F and 65% relative humidity until they reached equilibrium moisture content of about 12%. The pieces were removed from the room as needed and assembled into specimens with a nail, a T-nail, or a staple as quickly as possible. Specimens were then immediately subjected to lateral impact loading in the toughness machine or to lateral static loading in the universal testing machine.

The common nails used as controls were clinched by hand, as were some of the longer staples and T-nails. The majority of the clinched staples and T-nails were driven through the specimen against a steel backup plate. Some of the clinches were longer than generally accepted good practice, but this was to ascertain, if possible, whether the length of clinch would influence the performance of the fasteners when they were subjected to lateral loads.

Impact Loading

To conduct the impact loading studies, the adjustable weight of the pendulum was placed in the first position provided for it, and the pendulum was raised to an initial position of 60°. After the specimen was secured in the holding device, the pendulum was released and allowed to swing through its arc, pulling the chain taut and imposing a lateral impact force on the specimen. By use of the instrumentation previously described, the load-time pulse was recorded (Figure 4), and the final angle through which the pendulum swung was read from the vernier and scale associated with the drum of the machine.

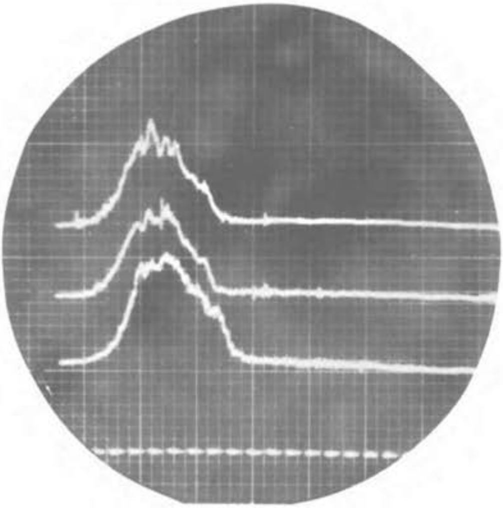

Figure 4 -- Example of pulse obtained with load cell and instrumentation setup for lateral impact loading of fasteners. Dashed line shows timing pulses at the rate of 150 per second.

From the calibration information and load-time pulse, the maximum load could be calculated. The timing pulses, occurring at a known frequency, permitted an estimate of the duration of the load in fractions of a second.

The final angle of the pendulum was used, with the conversion tables employed with the toughness machine, to obtain a value in inch-pounds that was an indication of the energy expended in causing failure of the specimen.

With any system of this type that involves a transducer, there is some question as to the accuracy of the system. Levy and Kroll (1) indicate that such systems may be expected to provide satisfactory accuracy if the period of the input pulse is three or more times the natural period of the transducer, and the damping coefficient is between 0.4 and 0.7 of the critical value when the input has the general characteristics of a triangular or sinusoidal pulse. Curves prepared by Levy and Kroll indicate that, as the ratio of the period of the input pulse to the natural period of the transducer increases, the response accuracy of the system tends to increase, even though the damping coefficient may be less than 0.4. Thus, if this ratio is high, the inaccuracy that can result from having a damping coefficient of less than 0.4 appears to be minimized.

Calculations and measurements and interpretations taken from load-time pulse traces indicated that: (a) the period of the signal pulse was about 300 times the period of the transducer; (b) the damping coefficient was somewhere between zero and the generally desired value of about 0.5; and (c) the load-time pulse traces that were obtained were generally similar to the first half of a sine wave.

Static Loading

To conduct the static loading studies, the specimens were clamped in the universal testing machine so that the crossarm of the T-shaped specimen was restrained. The movable head applied a tension force along the length of the stem so that the fasteners were loaded laterally in a manner similar to impact loading studies. The maximum load required to cause failure was obtained directly, as well as from a load-deformation chart. From this chart it was possible also to compute the average energy to maximum load. Because of the limitations of the recording system and the length of time required to subject each specimen to static loading, load-deformation curves were obtained only to maximum load.

RESULTS AND DISCUSSION

Impact Loading

The average maximum load as determined from the load-time pulse, and the average amount of energy required to cause failure of the specimen for each lot of 10 specimens of each of the four combinations, are given in Tables 1 through 4 (pages 66-71). Each combination was considered independently, and an analysis of variance was made for each group.

A combined plot using all values of maximum load against energy expended in causing failure of the specimen revealed no apparent relationship between maximum load and energy. An examination of the pictures of the load-time pulses substantiated this fact; some of the fasteners developed relatively high maximum loads, although only for short periods of time. For example, one lot had an average maximum load of 201.7 pounds with an average energy value of 69.5 inch-pounds when the average time of loading was 0.046 second. Other fasteners had somewhat lower maximum loads, but considerable energy was expended to cause failure of the specimen, because the duration of loading was longer. A second lot had an average maximum load of 70.3 pounds, but an average of 124.0 inch-pounds of energy was expended at the average loading time of approximately 0.064 second.

With any evaluation of this magnitude, and one which contains as many variables, numerous combinations exist that can be considered in presenting the results and in providing material for discussion. Since this investigation was primarily designed around container applications, and the combinations of specimens were selected as representative of those found in packaging, it seems reasonable to look at the results as they relate to the four combinations of wood specimens.

In fastening 1/4'' plywood to nominal 1'' material, some staples and some T-nails performed significantly better than the control nail; some performed significantly poorer; and some performed about the same as the control nail. It is interesting to note that this difference in performance is not always uniform in regard to average maximum load and the average energy that was expended to cause failure of the specimen. For example, there were instances where specimens with the alternate fastener required more energy to fail than the control nail, but carried a significantly lower maximum load. It appeared quite obvious, however, that the 18-gauge, narrow-crown staple with serrated legs was not only inferior to the control nail, but also generally exhibited a performance below that of the heavier gauge and wider-crowned staples.

In assembling two nominal 1'' pieces of white pine flatwise, neither staple nor T-nails performed too well in comparison with the control nail, regardless of whether the comparison was made on the basis of average maximum load or the average energy expended to break the specimen.

In fastening either 1/4'' plywood or nominal 1'' white pine to nominal 2'' southern yellow pine, the alternate fasteners were generally outperformed by the control nails in terms of the average maximum load developed by the fasteners in lateral impact loading. Comparing these same combinations of material on the basis of the average energy expended to cause specimen failure, the alternate fasteners generally performed at least as well as, and sometimes significantly better than, the control nail.

Visual observations of the specimen failures were also interesting. In Combination I (1/4'' plywood to nominal 1'' white pine), the fastener leg, or shank, generally pulled from the piece that held the point. This was also true for those fasteners that were clinched. There was an occasional failure where the crown of the staple or head of the T-nail pulled through the plywood, but there was no evidence of nailheads pulling through the plywood in the control specimens.

For those specimens in Combination II (two pieces of nominal 1'' white pine assembled flatwise), there was no instance of the staple crown or the head of the T-nail pulling through the material. Even with clinched fasteners, the leg or shank pulled from the piece containing the point.

This pattern of failure did not hold for Combination III (1/4'' plywood to nominal 2'' southern yellow pine). In this group, better than 35% of the T-nails and staples failed due to the crown or head pulling through the plywood, or else a combination of pullthrough of the fastener and shearing of the plywood at the fastener. The T-nails were worse than the staples, in that over 50% of the T-nails failed in this manner. There was some indication that the wider crown staples were more resistant to pulling through the plywood. Although the control nail generally failed in a similar fashion, the area under the head was somewhat larger, and thus the performance of the control nails was generally better than that of the other fasteners.

In Combination IV (nominal 1'' white pine to nominal 2'' southern yellow pine), the fasteners were driven through a considerably thicker piece than the plywood used and the failure was generally one of pulling the fastener from the nominal 2'' member. In less than 4% of the specimens was there any evidence of the fastener head or crown pulling through the material.

With the last two Combinations, III and IV, the hard summerwood bands, which are characteristic of southern yellow pine, influenced the results to some extent and were, no doubt, part of the reason for the somewhat wider variation in results.

Regardless of the specimen combinations, clinched staples generally outperformed unclinched staples. A comparison of the different lengths of clinch indicated that the optimum length of staple clinch was somewhat more than 3/32'', but no advantage was noticed for staple clinches exceeding 7/32''.

A statistical comparison of staple points indicated that chisel points rated significantly higher than divergent points, both in maximum load and in energy expended. This appeared to be particularly true when considering clinched staples.

The results did not indicate any definite advantage for either the 16 or 14 gauge staples nor for either the 3/8'', 1/2'', or 3/4'' crown width. The 18 gauge staples with serrated legs and 7/64'' crown were inferior to the nail controls and, in general, were also inferior to the other staples.

Comparison of the data indicated that there was no significant difference between similar products of different manufacturers, nor between leg or shank coatings used with the various staples and T-nails. Likewise, there was no definite pattern of superiority between the different gauges of T-nails.

Static Loading

Not all of the combinations of fasteners subjected to impact loading were subjected to static loading, but some studies were made of each of the four specimen combinations, including the use of control nails. The average maximum load to start failure, and the average amount of work done to maximum load, were computed from the load-displacement curve, and the average results are given in Table 5 (page 72). Each combination was considered independently, and an analysis of variance made for each group.

For these studies, when the piece holding the point of the fastener was white pine, the performance of the staples was as good as, or better than, the nail controls, both on the basis of average maximum load and average work to maximum load. When the piece holding the point of the fastener was southern yellow pine, the results were more erratic, with none of the combinations outperforming the control nails. The 13 gauge, 1-7/8'' long, plain T-nails and the 16 gauge, 2'' long, 7/16'' crown, plain galvanized staples, when driven through 1/4'' plywood into southern yellow pine, exhibited performances in static loading that were significantly less than the control nails.

In these evaluations there was a marked difference in the type of failure, depending upon whether the point of the fastener was in white pine or southern yellow pine. In Combinations I and II, where the point was in white pine, all of the specimens failed by starting to withdraw the fastener from the piece containing the point of the fastener. This was true regardless of whether 1/4'' plywood or nominal 1'' white pine was used in combination with the nominal 1 inch white pine cleat stock.

In Combination III (1/4'' plywood to nominal 2'' yellow pine), the heads of the T-nails and conventional control nails all pulled through the plywood. When staples were used, the failure appeared to be influenced by the orientation of the legs of the staple to the annual rings in the wood. If the staple entered the nominal 2'' block in a radial direction, so that the legs tended to be perpendicular to the annual rings, the crown of the staple pulled through the plywood. If the staple legs were tangential to the annual rings, the legs tended to pull from the nominal 2'' southern yellow pine.

When nominal 1'' white pine was fastened to nominal 2'' southern yellow pine (Combination IV), the head of the control nail generally started to pull through the nominal 1'' material, and then the white pine stem split at the nail. With staples, the legs generally pulled from the nominal 2'' southern yellow pine, although there were some instances where the crown had started to pull through before the legs pulled.

In comparing the results of static loading with those of the corresponding impact loading, it may be seen that the two test methods do not yield the same results. In general, the staples and T-nails performed better in relationship to the control nails, when subjected to lateral static loading, than when subjected to lateral impact loading, except when fastening 1/4" plywood to southern yellow pine. For example, the clinched 16 gauge staples used to fasten two nominal 1" pieces of white pine performed as well as, or better than, the control nail in lateral static loading, but the performance of similar staples in lateral impact loading was significantly poorer than the controls.

The results tend to verify previous exploratory work where controlled rough handling of a crate indicated that staples, though equivalent to nails in lateral static resistance, were not an adequate replacement when fastening 11/16" material to 11/16" material.

CONCLUSIONS

These conclusions are based only on the lateral impact studies and lateral static studies reported in this paper, and should not be confused with such other evaluations as conventional direct withdrawal.

1. There is no apparent relationship between the load-carrying ability of the fasteners and the energy required to cause failure of a specimen in lateral impact loading.

2. Staples and T-nails tend to perform better when clinched than when not clinched. This tendency is more prevalent when the fasteners are subjected to impact loading than when subjected to static loading. In addition, there appears to be an optimum length of clinch which is more than 3/32" but does not exceed 7/32".

3. For staples, the chisel point, or the divergent chisel point, appears to be better than the divergent point. This was not verified by the static tests, because the limited scope did not permit inclusion of a wide variety of staple points.

4. There was no significant difference in the performance of similar staples or T-nails supplied by different manufacturers.

5. Under impact loads, the wider-crowned staples appeared to be more resistant to pulling through the plywood.

6. Performance of similar staples in relationship to the control nails was not the same in static and dynamic loading, thus the static studies do not compare too well with the dynamic studies.

7. The species of wood influences the performance of the fasteners, particularly in static loading. In static loading, staples

could be expected to perform as well as nails when driven into such low-density species as white pine. With more dense species, such as southern yellow pine, the performance of the staples may be expected to be more erratic and not on a par with nails.

8. Since the two loading methods yielded different results, it appears that the results obtained from dynamic, or impact, loading are more applicable to the assembly of containers than are the results of static loading. Conversely, the static load results are no doubt more applicable to construction applications, such as the fastening of sheathing and plywood subflooring to studs and joists.

9. Staples of at least 16 gauge, 3/8'' or wider crown, coated or etched legs, chisel or divergent-chisel point, with legs long enough to provide at least a 3/32'' clinch, may be substituted for conventional nails to fasten 1/4'' plywood to nominal 1'' thick cleat stock. Similarly, T-nails may be used if they are at least 14 gauge with a coated or etched shank, and are long enough to provide at least 3/32'' clinch.

There is one characteristic of the impact loading method that should be investigated further. This is the possible "whipping" of the chain when it is drawn taut just before impact. This action may cause force components to be created on the fastener that are not strictly lateral. Similar tests using a pendulum-type impact tester may provide some information in this regard, and should be considered with a view toward improving the impact loading technique.

Since the work reported here is only a small portion of what could be done in this area, it would be desirable to conduct further studies aimed at answering some of the many questions that are still apparent.

SELECTED REFERENCES

1. Levy, Samuel, and Kroll, Wilhelmina D. "Response of accelerometers to transient accelerations," Journal of Research, National Bureau of Standards, Research Paper 2138, Vol. 45, No. 4, October 1950.

2. United States Forest Products Laboratory. Forest Products Laboratory Toughness Testing Machine. Forest Products Laboratory Report No. 1308, 1941.

TABLE 1 -- LATERAL IMPACT RESISTANCE OF 1/4 INCH, GROUP III, CONTAINER-GRADE PLYWOOD FASTENED TO 25/32 INCH WHITE PINE[1]

Fastener	Gauge of Fastener	Length of Shank or Leg	Coating of Shank or Leg[2]	Clinch[3]	Staple Crown Width	Type of Point[4]	Average Maximum Load	Statistical Comparison[5]	Average Energy Expended	Statistical Comparison[5]
		(in.)			(in.)		(lb.)		(in.-lb.)	
Nail	14	1-1/8	Plain	H			144.5		85.5	
Staple	16	1-1/8	Plain	H	1/2	DC	70.3	-	124.0	+
Staple	16	1-1/4	Plain	H	1/2	DC	100.9	-	153.8	+
Staple	16	1-3/8	Plain	H	1/2	DC	77.0	-	148.3	+
Staple	16	1-1/2	Plain	H	1/2	DC	100.9	-	168.6	+
Staple	16	1-5/8	Plain	H	1/2	DC	101.7	-	172.8	+
Staple	16	1-3/4	Plain	H	1/2	DC	83.4	-	178.8	+
Staple	14	1-1/8	Plain	H	3/8	C	129.3	√	172.1	+
Staple	14	1-1/4	Plain	H	3/8	C	114.6	-	142.6	+
Staple	14	1-3/8	Plain	H	3/8	C	146.0	√	170.2	+
Staple	14	1-1/2	Plain	H	3/8	C	113.4	-	186.6	+
Staple	14	1-5/8	Plain	H	3/8	C	117.6	-	165.1	+
Staple	16	1-1/8	Plain	N	3/8	D	67.6	-	71.1	√
Staple	16	1-1/4	Plain	H	3/8	C	96.6	-	152.1	+
Staple	16	1-3/8	Plain	H	3/8	C	151.6	√	150.5	+
Staple	16	1-1/2	Plain	H	3/8	C	202.8	+	156.3	+
Staple	16	1-5/8	Plain	H	3/8	C	115.7	-	168.9	+
Staple	14	1-3/8	Plain	P	3/4	C	136.2	√	223.1	+
Staple	14	1-1/2	Plain	H	3/4	C	208.7	+	268.9	+
Staple	14	1-5/8	Plain	H	3/4	C	168.7	+	248.2	+

Staple	16	1-1/8	Plain	N	3/4	D	69.3	-	78.9	√
Staple	16	1-1/4	Plain	P	3/4	D	133.7	√	163.9	+
Staple	16	1-3/8	Plain	H	3/4	C	128.0	-	174.8	+
Staple	16	1-1/2	Plain	P	3/4	D	119.8	-	152.6	+
Staple	16	1-5/8	Plain	H	3/4	C	95.0	-	173.0	+
T-nail	13-1/2	1-1/4	Plain	H			99.4	-	81.0	√
Staple	16	1	PG	N	7/16	DC	133.8	√	62.6	-
Staple	16	1	CTD	N	7/16	DC	160.4	+	70.3	√
Staple	16	1-1/4	PG	P	7/16	DC	110.7	-	110.0	+
Staple	16	1-1/4	CTD	P	7/16	DC	104.7	-	126.6	+
Staple	16	1-1/2	PG	P	7/16	DC	180.1	+	136.5	+
Staple	16	1-1/2	CTD	P	7/16	DC	178.7	+	154.2	+
Staple	16	1-1/8	PG	N	1	DC	107.3	-	68.5	√
Staple	16	1-1/4	PG	P	1	DC	128.4	-	96.0	√
Staple	16	1	PG	N	7/16	DC	143.3	√	57.3	-
Staple	16	1	CTD	N	7/16	DC	191.3	+	104.6	+
Staple	16	1-1/8	PG	P	7/16	DC	168.2	+	72.1	√
Staple	16	1-1/4	PG	P	7/16	DC	147.4	√	109.5	+
Staple	16	1-3/8	PG	P	7/16	DC	180.9	+	127.0	+
Staple	16	1-1/2	PG	P	7/16	DC	205.8	+	150.7	+
Staple	16	1-5/8	PG	H	7/16	DC	214.4	+	132.2	+
Staple	16	1	Plain	N	3/8	D	165.7	+	67.3	-
Staple	16	1	CTD	N	3/8	D	201.9	+	69.5	√
Staple	16	1	CTD	N	3/8	C	201.7	+	69.5	√
Staple	16	1-1/8	Plain	P	3/8	C	203.6	+	109.7	+
Staple	16	1-1/8	Plain	P	3/8	D	174.6	+	86.9	√
Staple	16	1-1/8	CTD	P	3/8	C	189.0	+	87.2	√
Staple	16	1-1/4	Plain	H	3/8	C	235.2	+	149.2	+
Staple	16	1-1/4	Plain	P	3/8	DC	114.5	-	123.7	+
Staple	16	1-1/2	Plain	P	3/8	D	187.8	+	130.2	+

(Concluded on next page)

TABLE 1 -- CONCLUDED

Fastener	Gauge of Fastener	Length of Shank or Leg	Coating of Shank or Leg[2]	Clinch[3]	Staple Crown Width	Type of Point[4]	Average Maximum Load	Statistical Comparison[5]	Average Energy Expended	Statistical Comparison[5]
		(in.)			(in.)		(lb.)		(in.-lb.)	
Staple	16	1-1/2	Plain	H	3/8	C	267.2	+	164.1	+
Staple	16	1-1/2	Plain	H	3/8	DC	250.3	+	139.4	+
Staple	14	1-1/4	Plain	H	3/8	D	292.0	+	159.1	+
Staple	14	1-1/4	Plain	H	3/8	C	371.0	+	224.4	+
Staple	16	1-1/8	Gal.	P	3/4	D	140.9	√	65.6	-
Staple	16	1-1/4	Gal.	P	3/4	D	206.7	+	123.0	+
Staple	18	1	Ser.	H	7/64	C	98.8	-	48.6	-
Staple	18	1	Plain	H	7/64	C	97.8	-	44.3	-
Staple	18	1-1/8	Plain	P	7/64	C	101.3	-	51.6	-
Staple	18	1-1/8	Plain	P	7/64	D	101.6	-	67.2	-
Staple	18	1-1/8	Ser.	P	7/64	C	87.9	-	43.7	-
T-nail	14	1-1/4	CTD	P			176.4	+	123.2	+
T-nail	14	1-1/2	Plain	P			199.9	+	141.9	+
T-nail	14	1-5/8	Plain	H			202.3	+	167.4	+
T-nail	14	1-3/4	Plain	H			187.7	+	145.2	+
Staple	14	7/8	Plain	N	13/16	D	234.8	+	69.5	√
Staple	14	7/8	CTD	N	13/16	D	220.5	+	73.4	√

[1] Each value represents the average of 10 specimens.

[2] PG--plain galvanized; CTD--cement or rosin coated; Gal.--galvanized; Ser.--serrated.

[3] N--no clinch; H--clinched by hand with hammer; P--clinched by driving through specimen against a steel backing plate.

[4] DC--divergent-chisel; C--chisel; D--divergent.

[5] + significantly more than control; - significantly less than control; √ not significantly different from control.

TABLE 2 -- LATERAL IMPACT RESISTANCE OF 25/32 INCH WHITE PINE FASTENED TO 25/32 INCH WHITE PINE[1]

Fastener	Gauge of Fastener	Length of Shank or Leg	Coating of Shank or Leg[2]	Clinch[3]	Staple Crown Width	Type of Point[4]	Average Maximum Load	Statistical Comparison[5]	Average Energy Expended	Statistical Comparison[5]
		(in.)			(in.)		(lb.)		(in.-lb.)	
Nail	12-1/2	1-3/4	Plain	H			263.0		160.0	
Staple	16	1-1/2	CTD	N	7/16	DC	167.2	-	73.8	-
Staple	16	1-5/8	Plain	P	7/16	DC	162.1	-	88.4	-
Staple	16	1-5/8	CTD	P	7/16	DC	181.0	-	102.6	-
Staple	16	1-1/2	CTD	N	7/16	DC	195.2	-	86.6	-
Staple	16	1-1/2	Plain	N	3/8	D	134.8	-	61.0	-
Staple	16	1-1/2	Gal.	N	3/8	DC	158.3	-	68.3	-
Staple	16	1-1/2	CTD	N	3/8	DC	163.6	-	93.8	-
T-nail	14	1-1/2	CTD	N			132.5	-	56.6	-
T-nail	14	1-5/8	Plain	P			135.0	-	80.3	-
T-nail	14	1-3/4	Plain	P			146.8	-	122.1	-
Staple	14	1-5/8	Plain	P	3/8	C	191.4	-	110.0	-
Staple	16	1-5/8	Plain	P	3/4	C	147.3	-	77.3	-
Staple	14	1-5/8	Plain	P	3/4	C	274.5	√	128.5	-
Staple	16	1-1/2	Plain	N	3/4	D	121.3	-	51.0	-
T-nail	12-1/2	1-1/2	Plain	N			164.6	-	82.4	-
T-nail	12-1/2	1-1/2	CTD	N			173.3	-	89.7	-
T-nail	13-1/2	1-3/4	Plain	P			197.8	-	120.3	-
T-nail	12-1/2	1-3/4	Plain	P			176.0	-	105.2	-
T-nail	13-1/2	1-7/8	Plain	P			225.1	-	191.4	+

[1] Each value represents the average of 10 specimens.

[2] CTD--cement or rosin coated; Gal.--galvanized.

[3] N--no clinch; H--clinched by hand with hammer; P--clinched by driving through specimen against a steel backing plate.

[4] DC--divergent-chisel; C--chisel; D--divergent.

[5] + significantly more than control; - significantly less than control; √ not significantly different from control.

TABLE 3 -- LATERAL IMPACT RESISTANCE OF 1/4", GROUP III, CONTAINER-GRADE PLYWOOD FASTENED TO 1-5/8" SOUTHERN YELLOW PINE[1]

Fastener	Gauge of Fastener	Length of Shank or Leg (in.)	Coating of Shank or Leg[2]	Clinch[3]	Staple Crown Width (in.)	Type of Point[4]	Average Maximum Load (lb.)	Statistical Comparison[5]	Average Energy Expended (in.-lb.)	Statistical Comparison[5]
Nail	11-1/2	2	Plain	H			431.5		227.5	
Staple	16	1-3/4	CTD	N	1/2	C	397.6	√	260.4	√
Staple	16	1-3/4	Gal.	N	1/2	C	375.8	-	244.9	√
Staple	16	1-5/8	Plain	N	3/8	C	351.8	-	166.1	-
Staple	16	1-5/8	Plain	N	1/2	C	332.8	-	248.2	√
Staple	16	1-5/8	Plain	N	3/4	C	341.0	-	218.8	√
T-nail	13-1/2	2	Plain	P			343.4	-	200.0	√
T-nail	12-1/2	2	Plain	P			358.5	-	219.4	√
T-nail	13-1/2	1-3/4	Plain	N			346.9	-	212.4	√
T-nail	13-1/2	1-3/4	Acid	N			344.8	-	202.2	√
T-nail	13-1/2	1-3/4	Gal.	N			334.5	-	216.4	√
T-nail	13-1/2	1-7/8	Plain	N			328.2	-	219.8	√
T-nail	13-1/2	1-7/8	Acid	N			338.0	-	206.7	√
T-nail	12-1/2	1-3/4	Plain	N			358.4	-	169.4	-
T-nail	12-1/2	1-3/4	CTD	N			362.7	-	214.6	√
Staple	16	1	PG	N	7/16	DC	273.0	-	101.0	-
Staple	16	1-1/4	PG	N	7/16	DC	341.9	-	153.9	-
Staple	16	1-1/2	PG	N	7/16	DC	378.9	-	215.9	√
Staple	16	1	CTD	N	7/16	DC	293.4	-	108.4	-
Staple	16	1-1/4	CTD	N	7/16	DC	324.0	-	145.1	-
Staple	16	1-1/2	CTD	N	7/16	DC	350.7	-	201.5	√
Staple	16	1-5/8	Plain	N	7/16	DC	338.1	-	201.2	√
Staple	16	1-5/8	CTD	N	7/16	DC	392.7	-	210.8	√
Staple	16	1-5/8	CTD	N	7/16	D	320.2	-	229.3	√
T-nail	13	1-7/8	Plain	P			304.1	-	162.4	-
Staple	16	2	Plain	P	7/16	DC	375.1	-	286.6	+
Staple	14	2	Plain	P	7/16	DC	431.4	√	216.7	√

[1] Each value represents the average of 10 specimens.

[2] CTD--cement or rosin coated; Gal.--galvanized; Acid--acid etched; PG--plain galvanized.

[3] N--no clinch; H--clinched by hand with hammer; P--clinched by driving through specimen against a steel backing plate.

[4] DC--divergent-chisel; C--chisel; D--divergent.

[5] + significantly more than control; - significantly less than control; √ not significantly different from control.

TABLE 4 -- LATERAL IMPACT RESISTANCE OF 25/32" WHITE PINE FASTENED TO 1-5/8" SOUTHERN YELLOW PINE[1]

Fastener	Gauge of Fastener	Length of Shank or Leg	Coating of Shank or Leg[2]	Clinch[3]	Staple Crown Width	Type of Point[4]	Average Maximum Load	Statistical Comparison[5]	Average Energy Expended	Statistical Comparison[5]
		(in.)			(in.)		(lb.)		(in.-lb.)	
Nail	10-1/4	2-1/2	Plain	H			397.4		190.4	
T-nail	13-1/2	2	Plain	N			270.9	-	223.6	√
T-nail	13-1/2	2	Acid	N			246.3	-	162.3	√
T-nail	12-1/2	2	Plain	N			279.6	-	217.4	√
T-nail	12-1/2	2	Acid	N			291.0	-	250.8	+
T-nail	12-1/2	2	CTD	N			305.3	-	269.8	+
Staple	16	2	Plain	N	7/16	DC	350.7	-	240.9	+
Staple	14	2	Plain	N	7/16	DC	335.9	-	300.6	+
Staple	16	2	CTD	N	7/16	DC	323.7	-	244.3	+

[1] Each value represents the average of 10 specimens.
[2] CTD--cement or rosin coated; Acid--acid etched.
[3] N--no clinch; H--clinched by hand with hammer.
[4] DC--divergent-chisel.
[5] + significantly more than control; - significantly less than control; √ not significantly different from control.

TABLE 5 -- AVERAGE RESULTS[1] OF LATERAL STATIC LOADING OF NAILS, STAPLES, AND T-NAILS

Fastener	Gauge of Fastener	Length of Shank or Leg	Coating of Shank or Leg[2]	Clinch[3]	Staple Crown Width	Type of Point[4]	Average Maximum Load	Statistical Comparison[5]	Average Work to Maximum Load	Statistical Comparison[5]
		(in.)			(in.)		(lb.)		(in.-lb.)	
(1/4 Inch Group III Container-Grade Plywood Fastened to 25/32 Inch White Pine)										
Nail	14	1-1/8	Plain	H			135		24.8	
Staple	16	1-1/4	PG	P	1	DC	139	√	78.0	+
Staple	16	1	PG	N	7/16	DC	136	√	70.0	+
Staple	16	1-1/4	PG	P	7/16	DC	176	+	48.0	+
(25/32 Inch White Pine Fastened to 25/32 Inch White Pine)										
Nail	12-1/2	1-3/4	Plain	H			129		46.7	
Staple	16	1-5/8	PG	P	7/16	DC	140	√	35.7	√
Staple	16	1-5/8	CTD	P	7/16	DC	188	+	55.7	√
(1/4 Inch Group III Container-Grade Plywood Fastened to 1-5/8 Inch Southern Yellow Pine)										
Nail	11-1/2	2	Plain	H			485		197	
Staple	16	1-5/8	CTD	N	7/16	DC	391	√	99.5	-
T-nail	13	1-7/8	Plain	P			310	-	74.0	-
Staple	16	2	PG	P	7/16	DC	341	-	78.8	-
(25/32 Inch White Pine Fastened to 1-5/8 Inch Southern Yellow Pine)										
Nail	10-1/4	2-1/2	Plain	H			392		117.4	
Staple	16	2	PG	N	7/16	DC	261	√	77.5	√

[1] Each value represents the average of five specimens.

[2] PG--plain galvanized; CTD--cement or rosin coated.

[3] N--no clinch; P--clinched by driving through specimen against a steel backing plate; H--clinched by hand with a hammer.

[4] DC--divergent-chisel.

[5] + significantly more than control; - significantly less than control; √ not significantly different from control.

Open Forum Discussion

Moderator - John S. Godley, Manager - Sales, Nelson Distributor Products Division, Gregory Industries, Inc.

Panel Members - Messrs. Countryman, Edmonds, Kurtenacker, Stern, and Wyckoff

D. C. Leavitt, MacMillan, Bloedel & Powell River, Ltd.: Spiral shank aluminum nails fastening an aluminum roof panel to a 3/8 inch fir plywood roof deck after two or three months' application can be removed with the fingers. Please give your comments.

Mr. Countryman: I haven't had enough experience with this particular type of application to make any definite recommendations about it, but it certainly appears that something must be basically wrong with the fastener. I presume there is quite a bit of dimensional movement, with the aluminum tending to exert a very strong withdrawal force on the fastener. Possibly this is one of the cases where screw fasteners should be strongly considered.

Mr. Stern: We have done some research along those lines. Changes are encountered in temperature. When the sun shines on the roof, the nail gets hot, and at night it gets cold. Continuous repetitive changes in temperature are exerted on the nail. The nail expands and contracts much faster than the wood expands and contracts. Therefore, the nail tends to back out. You can overcome this by using annularly threaded nails. These are prevented from backing out by the wood fibers which cantilever into the space between the annular rings. These wood fibers would have to be sheared off before the nail could back out. VPI Wood Research Laboratory Bulletin No. 42 on Nailing of Sheet Metal Roofing and Siding with Washered Roofing Nails describes this whole subject matter in detail.

Arthur Tisch, Independent Nail & Packing Co.: 1. What was the size of the control nail? 2. Are you able to draw any conclusions regarding the use of T-nails for lateral load transmission in trussed rafter construction?

Mr. Kurtenacker: In answer to the question about control nails, for each situation we used the nail as specified in container specifications relating to the simulated container combination. For example, in fastening the 1/4 inch plywood to the nominal 1 inch cleat stock, we used the conventional 1-1/8 inch duckbill nail. In heavier material, we had to use common nails in order to get a conventional clinch. All of the control nails and all of control specimens were clinched in accordance with the container specification requirements. The largest nail used was an 8-penny nail for fastening the 1 inch sheathing material to the 2 inch cleat stock. Am I able to draw any conclusion regarding the use of T-nails for lateral load transmission in trussed rafter construction? I think at this time I am not. Considering the applications that I think you had in mind, and the work that we've done, I don't think there is any parallel.

Jules Poupitch, Illinois Tool Works, Inc.: Do you think that the building industry is ready to accept deviation in fastening techniques other than the actual nails and screws?

Mr. Edmonds: I would say that it is. We are interested in any type of fastening system that is inexpensive, readily available, and will do a satisfactory job. We can be alienated from nails and screws at a moment's notice.

L. G. Derbyshire, General Electric Co.: Are charts available giving proper clearance hole and pilot hole diameters for type A screws? If so, where can these data be obtained?

Mr. Wyckoff: There are charts available and one place, among others, where you can obtain them would be our company. Any manufacturer of screw products, I am sure, has charts covering many of the conditions you might be interested in.

C. H. Topping, E. I. du Pont de Nemours & Co.: Do you know of a satisfactory blind fastener for prefinished plywood which will have a pullout of at least 15 pounds in 3/8 inch plywood?

Mr. Countryman: We have at least one fastener for prefinished plywood which will have a pullout in excess of 15 pounds. It is only in the developmental stages, and I am not at liberty to talk about it to any great extent, but it does look very promising and capable of being manufactured relatively inexpensively. The techniques of application have to be worked out, considering all of the factors--for example, what the application is, whether it's outside siding or inside paneling, etc. There are various handling factors and appearance factors to be considered. I can say only that we are working on it, and I know that other organizations are working on such fasteners also.

Mr. Edmonds: If I might add to that, we have a type of movable asbestos-cement wall, used for interior application, and we install sheet buttons on the back of the asbestos-cement board by use of an expansion type of fastener. After a pilot hole is drilled on the back face of the board, this fastener is inserted, and then the screw that is put in expands the fastener which then locks to the asbestos-cement. This, I must admit, is not nearly as strong in laminar strength as plywood, so I would think that you could very readily get 15 lb. of holding power with a blind fastener in plywood. This sheet button which is only about 1/4" in depth, is then inserted in a slotted stud, and the panel is held in position. It's made by a manufacturer in New England, and we've found it to be a very satisfactory fastener.

Jules Poupitch, Illinois Tool Works: Do you find an increasing use of steel in structural members (studs) over conventional 2 inch x 4 inch wood? If so, how fast is it increasing?

Mr. Godley: I speak simply from reading a number of construction magazines and traveling about the country watching new construction go up, but I think there is an increase in the use of steel. It's difficult to determine how rapid that increase is, but there is a considerable amount of steel studs going into place--more than in the previous few years.

M. H. Johnson, University of Florida: It seems unusual that the tear-off resistance of staples in asphalt shingles has proven to be greater with the staple crown (axis of the points) perpendicular to the eave, than with the axis parallel. Please elaborate.

Mr. Edmonds: Normally, you would think (and we thought for quite a time) that placing the staple in a position parallel to the butt of the shingle would be the ideal, or the strongest, way to apply the staple, because then the two legs of the staple act to resist tear-off or blow-off of the shingle. We ran a series of pull-off or blow-off tests that way, then we applied the staple at a 45° angle and found that our results were a little bit better. Then, to go whole hog, we installed the staples perpendicular to the eave. As you point out, you'd think that tear-off resistance would be lowest, since you've only got one leg of the staple which is tending to keep the shingle from tearing up.

In the manufacture of asphalt roofing, we use an asphalt-saturated rag felt coated with the granules, and this is manufactured in continuous sheets. The shingles are then cut in three strips. They go through a cutter roll, and the tabs are cut out. Asphalt felt has a grain or direction to it, very much as wood has. In the felt are a series of strands. It is stronger in its longitudinal direction than in its vertical. Thus, the staples that are applied vertically, or at right angles to the eave, tend to catch more of the strength of the felt in the direction of its greatest strength, and there is more resistance to tear-off. If we apply the staples parallel to the eave, very often these staples will fall between several lines of the strength of the felt, and then you get no resistance, or very little resistance, to tear-off. When we apply the staples at a 45° angle, we are catching a little more of the strength, or the grain, of the basic felt that is used for the asphalt shingle.

D. C. Leavitt, MacMillan, Bloedel & Powell River Ltd.: What type of nail would you recommend to provide maximum pressure for glue-nailed plywood fastened to a lumber component, keeping in mind the nail must be coated to retard staining?

Mr. Stern: I think coating is a very unsatisfactory way of preventing staining of the plywood, because the coating is disturbed in its continuity by hammering and pin holes. Therefore, any moisture getting to the nail, or whatever is used for a fastener, will eventually start rusting and discoloration of the surface of the plywood. As far as the nail is concerned, a properly threaded nail provides high pressure. If shear load is to be transmitted, it should be a helically threaded nail which has much better holding power than a common nail, a staple or a T-nail. If uplift 'resistance or withdrawal resistance is the criterion, the annularly threaded nail gives the best performance. It is a question of application, or end-use of the particular joint.

Mr. Countryman: We have run some rather extensive tests in an attempt to develop adequate schedules for making nail-glued joints. The assumption is usually made (and I think it is pretty well borne out by facts) that once the glue is set the nail ceases to function in transmitting shear or developing withdrawal resistance to the joint. So, we are primarily interested in the few hours while the flue is setting. As a result of a rather elaborate series of tests, we finally came to the conclusion that the type of nail and the holding power of the nail are not too important. We tried a very strong ring shank type of nail. I think they were 6-penny common, and we tried rather small, smooth shank, cement-coated nails. It appears to be more a question of getting enough of them in there, in nailing plywood to lumber at least, to make sure that there is fairly uniform contact.

Generally speaking, you are talking about nailing along a 2 inch, or possibly wider, surface. So, it's a matter of getting the right spacing, and not so much of getting the right nail. Apparently a minimum size nail would be best. We recommend a 4-penny nail for 3/8 inch plywood and a 6-penny nail for thicker plywood, with certain spacings running on the order of 3 to 4 inches. The most important factor, actually, is to have a smooth surface. A smooth lumber surface is very essential in nail-gluing. Of course, close tolerances of fit between members are also important. As far as the corrosion resistance is concerned, I think any common galvanized, hot dipped galvanized, or aluminum-type nails are quite satisfactory. They don't affect the ability of the glue to set under pressure.

Ernie Schau, Practical Builder magazine: How can your findings be applied to the field of construction? Can you make any recommendations for use of T-nails in residential structures, for example?

Mr. Kurtenacker: I don't believe that I am in a position to make any recommendation regarding these particular fasteners. The sole purpose of the discussion was to present what we know about them at this time. I believe that there is a considerable amount of information yet to be gained about these particular fasteners. I do know of instances where they are being used in certain types of house construction. What the success of the fastener is, I do not know.

L. K. Grimes, Bostitch Co.: Both staples and T-nails are used in house construction and in the attachment of both the plywood-type diaphragms and roof sheating. This is very satisfactorily covered in UM-25 put out by FHA in 1958.

Jules Poupitch, Illinois Tool Works: Is there any hope or future for a nail made of sheet material rather than heading from wire?

Mr. Stern: Several such nails, made out of sheet metal, have been on the market. One is the ES-nail. As always, limitations exist. The ES-nail has not been used much because of its particular limitations. I have been particularly intrigued by a sheet metal nail which was invented by an Austrian some six or eight years ago. It has not been put in production. Again, it has limitations, but for certain purposes, it appears that it has much promise. It's much too early to talk about it, however, since there is no manufacturer as yet making such a nail.

Leo Goldstein, City of Philadelphia: Nails and screws are not limited by a standard giving minimum chemical and physical characteristics, as is true of most other building materials. Why are there no ASTM specifications for the various wood fasteners?

Mr. Edmonds: As far as we are concerned, since there are no specifications as such, we always refer in our instruction sheets to a particular kind of fastener for use with our materials. With our asbestos-cement siding shingles, we call for an aluminum nail. We will not approve the use of any type of a galvanized steel nail, because we have had difficulty with rusting. There again, there are no standards that we know of to govern the type of galvanizing or the thickness of galvanizing on the nail. With the great number of nails now present on the market that are of minor quality, a lot of them imported, we have to stay pretty close to a standard recommendation such as that. Of course, if nails are being used in a place where rust or humidity is not a problem, or where appearance is not a problem, then we are satisfied to use a common wire nail. For instance, in applying our sheathing board to studs, it is always covered with a finishing material. Therefore, we will accept the use of any common nail, as long as it is of the prescribed gauge and length.

Arthur Tisch, Independent Nail & Packing Co.: An application has been filed for a commercial standard on aluminum nails. A commercial standard is contemplated on special nails, and is presently under preparation by the newly formed trade association, Special Wire Nail Manufacturers of America. This same group is presently recommending revisions to Federal Specification FF-N-105 which will be completed in the very near future. There is one ASTM specification on nails, ASTM C380-58T. This covers annular threaded drywall nails, and it is my opinion that ASTM takes a rather dim view of this approach to nail specifications. There are over ten thousand special fastenings being used in the building industry, and a specification covering each one would be out of the question. Professor Stern, under the auspices of ASTM Committee D-7, is preparing a glossary of terms used in the nail industry, and has found countless definitions for the same words. Over the centuries, the nail industry has fallen into a state of chaos in this respect, and it is the hope of the Special Wire Nail Manufacturers to bring order out of this chaos.

Mr. Wyckoff: I would like to comment on this, because I think it's an extremely appropriate question. We must recognize the fact that, for example, raw material manufacturers have specifications covering raw materials. The American Screw Association has standards covering thread depths and height of head and of data of that type. We have a certain amount of data developed by this BRI Committee, but we haven't pulled these all together. Therefore, this poses a difficult problem for you, the user or the designer in the building industry. Because the data are so widely scattered, our Committee, beginning with BRI 1960 Fall Conference on Mechanical Fasteners for Industrial Curtain Walls, began a program of assembling and developing performance information. We hope that this will be continued, and that some useful performance criteria will result which will be a guidepost, not for fasteners in general, but for the building industry in particular.

Ernie Schau, Practical Builder magazine: Will you discuss the discrepancies in the threaded nails you called "insufficiently deformed" or "unsatisfactorily threaded?"

Mr. Stern: Quite a lot of know-how is necessary in the designing of improved nails. There can be a lot of variations. For instance, the threads can be deep or shallow, they can be closely spaced or farther apart, the angle of the thread can be steep or the opposite. The face angle of the thread itself can be such that the fibers slide over the thread, or are restricted from sliding. In short, there are many factors which influence nail performance. There are isolated physical and mechanical properties of the wire, the stiffness of the wire--all of them are of influence upon the performance of the nail. You have to have a good nail in order to get the performance that you want.

W. Oberdick, University of Michigan: Were you concerned with end-use requirements in your studies? if so, how did you determine the quantitative values for lateral resistance required of a nail?

Mr. Stern: I didn't go into detail in my presentation. To begin with, we tested plywood of different thicknesses, the thinnest being 3/8 inch diameter, and the thickest being 1 inch diameter. Thus, we covered the whole range of thickness of commercially available plywood. We performed basic tests. Hence, the presented information can be applied to all kinds of conditions. We performed withdrawal tests and lateral loading tests. We determined the effectiveness of the nails at small as well as large deformations of the joints. We used different edge distances in order to simulate the varying conditions. We performed immediate and delayed tests in order to simulate short- and long-time use conditions of the structure. It appears that the data we produced are such that they can be applied to any climatic and use conditions normally encountered in the field. The fastener must be selected for the particular condition involved. All test values are of a comparative nature. Hence, fastener selection is easy upon determination of existing forces.

Leo Goldstein, City of Philadelphia: There has been no discussion of truss-connectors (rings, toothed, common-plate penetration such as the gangnail, etc.). Is such a discussion planned in the near future? To what degree does the common plate compensate for smaller penetration usually found in this type?

Mr. Godley: In answer to the first question, it is not currently on our agenda, but I would suspect that it will be, because here is a whole area that we were unable to cover in this conference.

Mr. Goldstein: I am talking about a truss-connector in which the protrusions cantilever from the metal plate. Slots are punched out, and slot material is then bent down to form nails, but they still are attached to the plate. Then the whole thing is pushed into the wood. Generally, the protrusions have lesser penetration than would be required for individual nails. To what degree does this compensate for the fact that you don't have as much penetration into the wood as you would with individual nails?

Mr. Stern: Actually these prongs or teeth as we call them, create friction between metal plate and wood to transmit shear loads. However, in most cases, they do not hold the plate to the wood. For this reason, nails are needed to hold the plate to the wood, particularly when the wood shrinks, to prevent the plate from falling off. The prongs are to transmit shear loads just like ring-connectors which are inserted into the wood to transmit the shear load in big trusses. Consequently, we have a large number of small prongs or teeth for effective load transmission in shear only. Nails are required in most cases to hold the plate to the wood and to keep the prongs in the wood.

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