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**RESEARCH  
ON  
MECHANICAL FASTENERS  
FOR RESIDENTIAL CONSTRUCTION IN CANADA**

by  
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Sommaire en français

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## S U M M A R Y

The Forest Products Research Branch of the Department of Forestry of Canada has been interested in research on mechanical fasteners for wood for nearly 50 years. This research has not been directed toward the accumulation of large volumes of data on the strength of fasteners but rather toward obtaining a better understanding of the many factors which influence fastener behaviour. Other organizations have also been active in fastener research in Canada, including nail and staple manufacturers, universities, and other government departments. For many years the chief role of the FPRB in fastener research has been the evaluation and appraisal of new fasteners and fastening systems for the purpose of providing comparative strength and performance data to Central Mortgage and Housing Corporation. This is the organization which, in Canada, administers the National Housing Act and which guarantees long-term mortgages on family dwellings.

## S O M M A I R E

La Direction des recherches sur les produits forestiers du ministère des Forêts du Canada s'intéresse depuis 50 ans aux recherches sur les attaches à bois. Au lieu de servir à accumuler des quantités de données dans des volumes, ces recherches ont plutôt pour but de parvenir à une meilleure compréhension des nombreux facteurs qui influent sur l'efficacité des attaches. D'autres organismes du Canada ont aussi poursuivi des recherches sur les attaches, notamment des fabricants de clous et de crampons, des universités et d'autres organismes gouvernementaux. Pendant de nombreuses années, le principal rôle de la DRPF en matière de recherches sur les attaches a consisté à évaluer et à expertiser les nouveaux modèles d'attaches et de dispositifs d'attache, et de fournir des données concernant leur solidité et leur efficacité à la Société centrale d'hypothèques et de logement. La Société est l'organisme canadien chargé d'administrer la Loi nationale sur l'habitation et qui se porte garant des hypothèques à long terme sur les maisons d'habitation.

RESEARCH ON MECHANICAL FASTENERS  
FOR RESIDENTIAL CONSTRUCTION IN CANADA\*

by

D.E. Kennedy

INTRODUCTION

The Forest Products Research Branch (FPRB) of the Department of Forestry of Canada has been interested in research on mechanical fasteners for wood and wood products since the formation of the Forest Products Laboratory prior to World War I. While the work carried out by this and other Canadian organizations has not resulted in the publication of large volumes of data on the strength and performance of mechanical fasteners, it has led to a better understanding of the problems involved in the use of fasteners, with a special emphasis on nails. Work has also been directed toward the solution of particular problems peculiar to Canadian conditions. The tendency has been to draw heavily on the large volume of research data which are available in other countries, particularly the United States, and to complement these data with additional research to make them more adaptable to Canadian conditions. However, Canadian research organizations have embarked on new and original research in the field of mechanical fastenings whenever there was a need for such information.

The nail is the most common mechanical fastener used in residential construction, being able to perform its function because of its resistance to withdrawal and to lateral displacement in the wood. At first thought it would seem to be a relatively simple matter to evaluate these properties by test. However, FPRB experience over the years has shown that the development of reliable and consistent data on the shear strength and withdrawal resistance of nails is one of the most difficult and

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\* Paper prepared for Building Research Institute Fall Conference on Significance of Mechanical Fasteners in Residential Frame Construction held at Mayflower Hotel, Washington, D.C. November 19-21, 1963.

frustrating fields of research. This is the main reason why this Branch has not attempted to publish data on the withdrawal resistance and shear strength of nails and, instead, has confined its activities mainly to the solution of individual problems as the need arises.

In the 1920's and early 1930's, the Forest Products Laboratories of Canada, as the FP&B was then called, were engaged in a systematic study to determine the withdrawal resistance of nails from the various commercial species of wood most common in Canada. This study was carried on in conjunction with the systematic sampling and testing of small, clear specimens of Canadian woods to determine their various mechanical and physical properties. Sections of each bolt or log were set aside and reserved for testing to determine the nail withdrawal resistance of the various species. No international standard for the testing of nails existed at that time. Hence it was necessary to develop a method which could be employed by personnel at each of the two laboratories, in Montreal (now in Ottawa) and Vancouver. It was recognized by the research workers at that time that the method of driving the nail could conceivably have an effect on its withdrawal resistance. Accordingly, a tool was developed which facilitated the driving of the nail into the wood by the same testing machine which later withdrew the nail. Research workers of that day were apparently convinced that this simple and seemingly foolproof test method could be used by different personnel in each of the two laboratories at different times and still provide reliable and consistent test data. After several years of work it was found that this was not so.

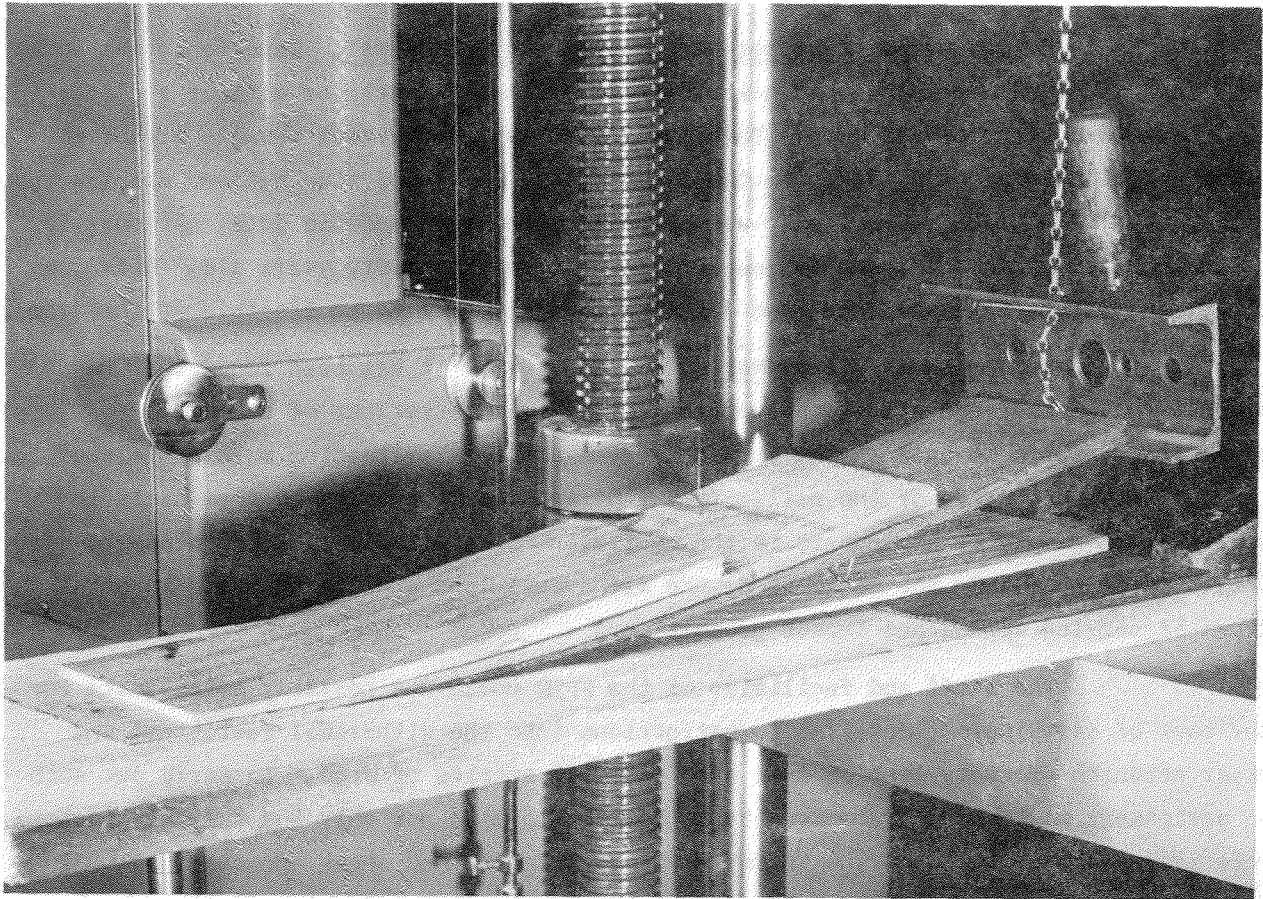
It was found that conflicting results were obtained by personnel at each of the two laboratories. It was also found that different personnel at the same laboratory could not always obtain the same result when using the identical technique on the same tools and on the same machines. This brought about a more careful examination of the various factors which might influence the withdrawal resistance of nails with a view to designing a test method which would effectively eliminate all of the unwanted variables. Some of these variables were found to be as follows:

1. The nail itself. At least two gauge systems have been used for measuring the diameter of the wire used in nails sold in Canada. These are the British Imperial wire gauge and the American Steel and Wire Company gauge. The existence of these two gauges is confusing to the user who is usually unaware of the actual nail diameter and cannot, therefore, be certain of the data he is using.

2. Surface finish. As nail making machinery has been improved over the years, it is not surprising that the finish obtained on the nail surface has undergone a corresponding change. While the nail surface may appear smooth to the naked eye, slight irregularities can increase or decrease the friction between the nail and the wood by an appreciable amount.



3. Contaminating oils and greases and other foreign material on the nail surface. These can bring about fairly large differences in the withdrawal resistance of a smooth shank nail. While it is a simple procedure in the laboratory to scour the nail surface and remove all foreign material, this precaution is questionable because it tends to yield laboratory test data which are in no way related to actual conditions. Perhaps the simplest way of overcoming this problem is to nail two pieces of wood together and to carry out the test by separating the two pieces of wood. The first piece of wood through which the nail is driven removes the greater portion of any contaminating material on the surface of the nail so that the portion of the nail entering the second piece of wood is relatively clean. This type of test has the additional advantage in that it corresponds more closely with actual conditions. It also provides a realistic test result in the case of some special nails which exhibit such tenacious withdrawal resistance that failure frequently takes place by pulling the head through the first and thinner piece of wood.



FPRB 2-593

Figure 1 — Cedar shingles being subjected to an uplift test using a tool which grips the underside of the butt end of the shingle.

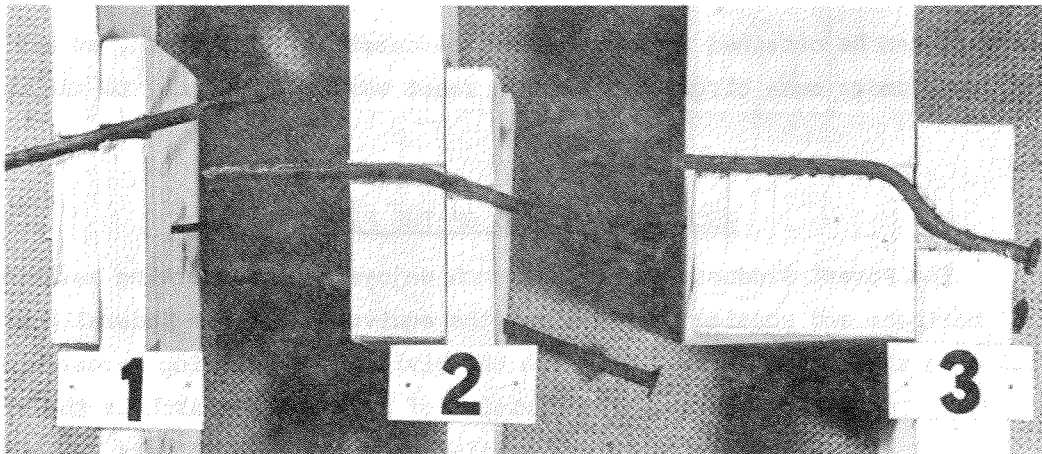
4. Method of driving. Nails for test purposes can be driven manually by means of a hammer, or by means of a special tool attached to the testing machine, or by means of automatic power-operated driving devices. One cannot expect to obtain the same withdrawal resistance from similar nails driven by different methods.

5. Moisture content of the wood. It is well known that the moisture content of the wood will affect the withdrawal resistance of the nail. Not only does the immediate withdrawal resistance of a nail vary as a function of the moisture content of the wood, but the withdrawal resistance will change if the moisture content of the wood changes between the time of driving and the time of withdrawal. This presents a very serious problem to a laboratory which is attempting to provide usable design data to engineers or architects. It is not always possible for engineers and architects to predict the changes in moisture content which may take place in wood joints. Even if these changes in moisture content can be predicted, the complications involved in allowing for such changes become so serious that engineers and architects would rather sacrifice ultimate economy in favour of simpler, more conservative, design methods.

6. Length of time between driving and withdrawal. Experience has shown that the withdrawal resistance of nails can vary with time, with or without a change in the moisture content of the wood. This means that laboratory test results are of no value unless they are considered in the light of the length of time between driving and withdrawal. The practical everyday use of nails demands dependable data, not only for nailed joints one day old, but for nailed joints twenty to fifty years old. Unfortunately, laboratory tests of such long duration do not appear to be feasible at this time.

7. Speed of withdrawal during the test. It has been found that the speed of withdrawal can affect the apparent withdrawal resistance of nails by very large percentages. This means that the standard speed adopted for testing must be related to the end use application of the nail. The withdrawal force applied to some nails in practice can safely be assumed to be the equivalent of a withdrawal speed close to zero inches per minute. On the other hand, the withdrawal load applied to nails in other types of service approaches impact proportions.

The staff and facilities of the FPRB could not possibly be adequate for the task of carrying out detailed investigations into the withdrawal resistance and shear strength of every type of nail used in every species of wood. To carry out such an assignment would be a tremendous task, bearing in mind not only the variable factors referred to above, but also the infinite variety of deformed shank and other special nails which have been brought on the market in recent years and which continue to be developed in ever-increasing variety. Therefore, it has been found necessary to confine the work to that which is directed primarily at the solution of everyday practical problems.



FPRB 2-853

Figure 2 — Three different forms of nail joint failure caused by variation in thickness of wood members.

#### INDUSTRIAL RESEARCH

In addition to the research on nails and other mechanical fasteners for wood which has been carried out at the FPRB, research has been conducted by industry, by universities, and by other government departments. Research at universities is usually carried out by students seeking advanced degrees. The results of this research are generally written up in theses which, unfortunately, are usually buried in university libraries where often they become lost to posterity. The author is not aware, therefore, of much nail research which has been carried on in Canadian universities although it seems very likely that a considerable amount of such work must have been undertaken over the years. However, it is known that research has been carried out on mechanical fastenings by industry. Some of this has been conducted in company-owned research laboratories while other research has been performed by commercial testing laboratories or universities on a custom basis and paid for by the company concerned. Examples of this type of research include the work that has been done on special types of deformed shank nails. The various manufacturers of staples and power-driven nails have also been active in the field because they have found it necessary to provide information on the withdrawal resistance and shear strength of their fastenings in order to obtain acceptance from building officials.

All research on mechanical fastenings, whether carried out by industry or government organizations, is potentially very valuable in filling existing gaps in our store of scientific data on this subject. However, industries carrying out research should be especially careful to avoid the temptation to slant their research results in order to show their product in the most favourable light. Any of the variables previously enumerated can throw a bias, intentional or otherwise, into the test results.



The benefit that can be obtained from biased or inaccurate test data can, at best, only be temporary and, under some circumstances, can react very unfavourably to the industry concerned.

#### RECENT ACTIVITIES OF THE FPRB

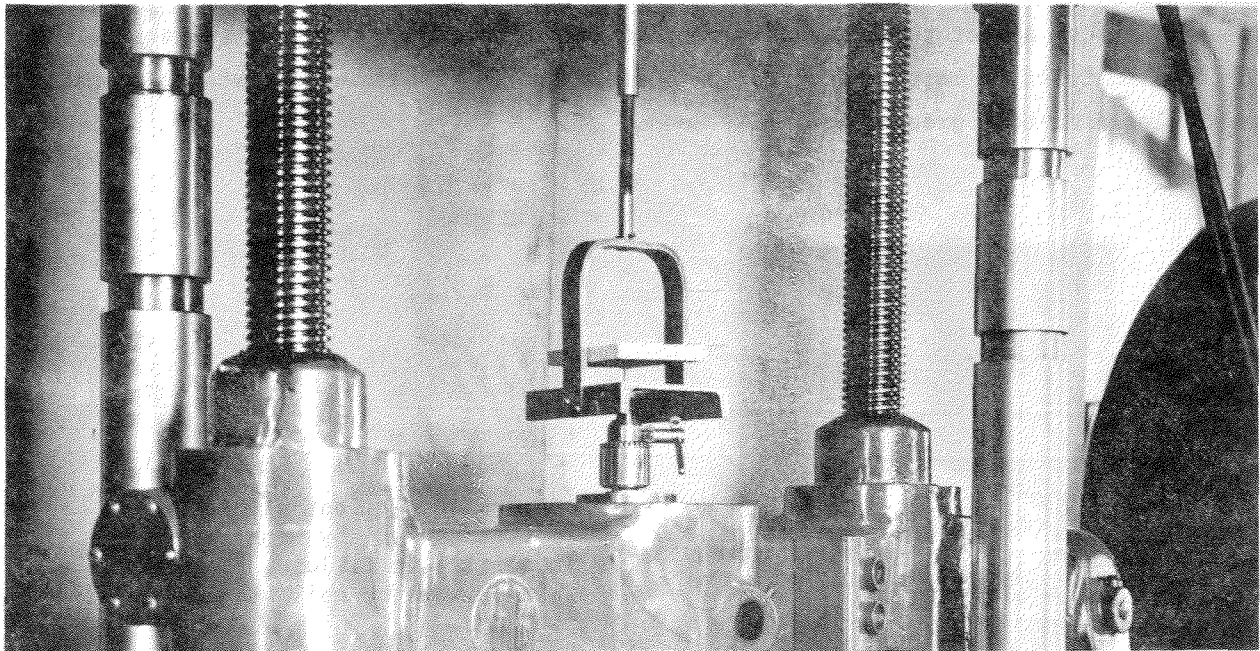
The Forest Products Research Branch enjoys a close working relationship with Central Mortgage and Housing Corporation (the equivalent of the Federal Housing Administration in the United States) and with the Division of Building Research of the National Research Council of Canada. The Division of Building Research is the official adviser to Central Mortgage and Housing Corporation on scientific matters relating to building construction. By special arrangement among the three organizations, however, the FPRB has become the recognized adviser to the Corporation on technical matters concerning wood. In this capacity, the FPRB has been called on frequently for advice concerning the adequacy of many mechanical fastening systems.

One typical example took place about ten years ago when one of Canada's leading steel companies produced a new type of deformed shank nail which they proposed to market primarily for housing construction. This nail had been developed by the company and had been tested by their own research laboratory. It was made of a higher carbon steel than the ordinary common nail and, because of its deformed shank, was more costly to produce on a cents-per-nail basis. Partly to make the nail competitive, and partly because the company sincerely believed that the nail had much superior withdrawal resistance, the proposal was made that a  $2\frac{1}{4}$ -inch special nail might replace a  $2\frac{1}{2}$ -inch common nail. This proposal was submitted to Central Mortgage and Housing Corporation, and, along with this request, data were submitted indicating that the  $2\frac{1}{4}$ -inch special nail had about twice the withdrawal resistance of a  $2\frac{1}{2}$ -inch common nail. The FPRB was consulted and asked to carry out a program of confirming tests. This was agreed to.

However, the FPRB tests indicated that the withdrawal resistance of the  $2\frac{1}{4}$ -inch special nail was not twice but only half that of the  $2\frac{1}{2}$ -inch common nail. The steel company was naturally very concerned at these conflicting results and sent its Director of Research and Vice-President of Sales to Ottawa to discuss with FPRB personnel possible reasons for the discrepancy. Testing was resumed and every attempt was made to uncover some slight difference in testing technique which could account for the wide range in values obtained by the two laboratories. It was finally discovered that the steel company had been withdrawing nails at a speed of 3 inches per minute. The FPRB had been withdrawing the nails at a speed of 0.05-inch per minute. At the slower speed, the  $2\frac{1}{2}$ -inch smooth shank common nail had approximately twice the withdrawal resistance of the  $2\frac{1}{4}$ -inch deformed shank nail. However, when the speed of testing was increased to 3 inches per minute, the results were reversed. Furthermore, it was found

that, by varying the speed of testing in increments from 0.05 to 3-inch per minute, the point at which apparent equality of the nails occurred was at a speed of approximately 0.1 inch per minute.

This and other investigations have combined to convince the FPRB that dependable, reproducible data on the withdrawal resistance of nails are difficult, if not impossible, to obtain. On the other hand, much less difficulty is experienced when simple comparisons are made between the strengths of various types of fasteners. Strength comparisons, as opposed to actual strength determinations, tend to lend themselves more to the solution of practical problems in house construction. There are

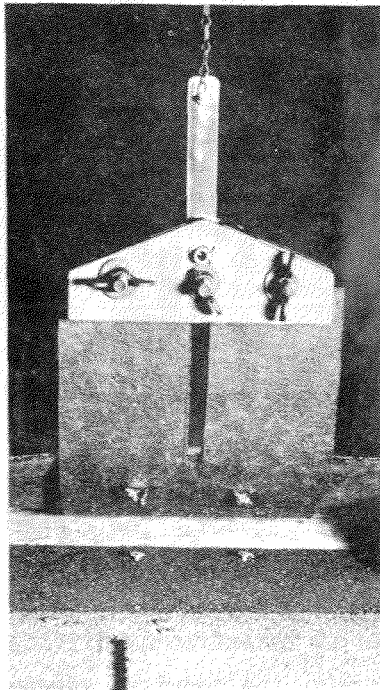


FPRB 2-805

Figure 3 — Nail head pull-through test on insulating fibreboard. The shank of the nail is gripped by the Jacobs chuck.

innumerable situations in the average residence where it is extremely difficult to compute the stresses imposed on a fastening and to determine the required strength of the fastening to resist these stresses. But long practical experience has shown that a particular fastening used in a particular way will perform a satisfactory job. Therefore, when an alternative type of fastening is proposed the simplest procedure is to make a comparison with some previously accepted type. While this may appear to be an unscientific and primitive approach to the problem, and while it has some limitations, it nevertheless provides a means of avoiding most of the many pitfalls which are inherent in strength determinations as such.

Now, when the FPRB is asked for information on a new type of fastening by some organization such as Central Mortgage and Housing Corporation, the investigation usually takes the form of a comparison between this new type of fastening and a conventional fastening which has been found to do an adequate job. The same operator is used to carry out the whole series of comparative tests, using the same testing machine, and the tests are completed in a relatively short period of time. The variability inherent in any wood species is simply overcome by using the same piece of wood for both types of fastener and by driving the fasteners alternately along the length of the same piece. Even this type of testing, which has been found to be more fool-proof than others, may be subject to some criticism. For one thing, it is difficult, with the time normally available for such investigations, to delve deeply into the time aspects as they affect the strength of mechanical fastenings. However, it is possible to investigate other matters such as the differences in withdrawal resistance of nails or staples from both green and air-dry wood.



FPRB 2-540

Figure 4 — Test simulating uplift caused by high winds resulting in failure of asphalt shingle by nail head pull-through.

The trend toward the development of special types of nails and staples and of mechanical means of driving has been very pronounced over the last ten or fifteen years. Encouragement should be given to the use of mechanically-driven nails and staples because of the tremendous saving in labour which may result. On the other hand, attempts at saving labour should not be permitted to reduce the overall quality of the finished

house. A tendency has been observed on the part of some to believe that staples have magic powers of withdrawal resistance which is not possessed by nails. The author has not found this to be true. A smooth shank staple derives its withdrawal resistance in the same way that a nail develops its withdrawal resistance, by friction between the surface of the staple leg and the wood. It follows, therefore, that a smooth shank staple should present approximately the same surface area in contact with the wood as the smooth shank nail that it is intended to replace if it is to be expected to develop the same withdrawal resistance. This has been generally confirmed by tests. Some staples are designed to diverge as they are driven into the wood. This is claimed by some to develop a much higher withdrawal resistance than would otherwise be the case. However, experience has shown that diverging staple legs produce only a small increase in the withdrawal resistance of the staple. Nevertheless, a quite different result can be expected if the points of the staple are clinched on the opposite side of the wood through which they are driven. The difference between a gentle curvature of the legs within the wood itself and a sharp bend on the opposite side of the wood can make for a very pronounced difference in withdrawal resistance.

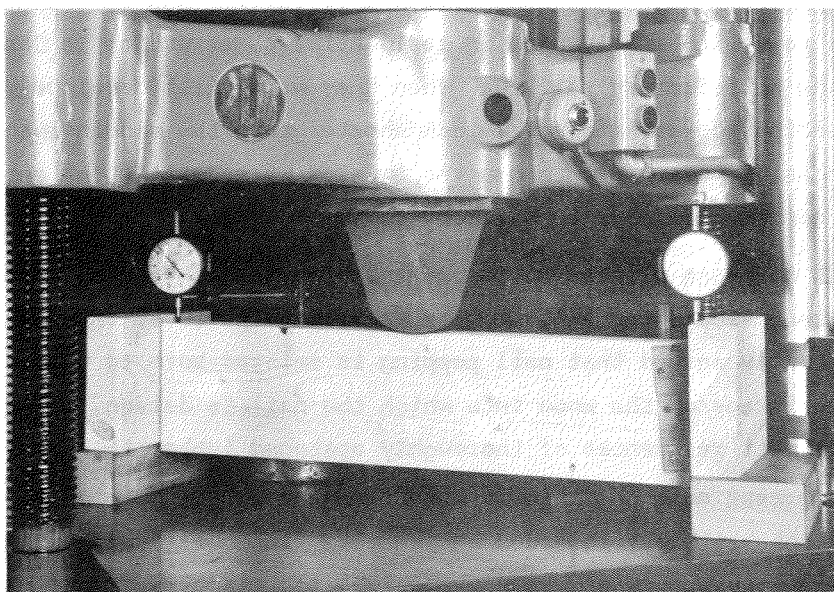
The use of deformed shank nails appears to be on the increase in Canada. One of the most popular of these is made from steel wire of square cross-section which is twisted into a helix before it is passed through the nail making machine. The withdrawal resistance of this type of nail appears to be superior to that of a common smooth shank nail of approximately the same gauge and length for most applications and under most conditions. However, it is inferior to the type of nail which is manufactured by upsetting a sharp and pronounced helical thread as a second step in the nail manufacture. Twisted nails are now being widely used in residential construction in Canada and they appear to be giving satisfactory service. When they were first developed, they were recommended in lengths approximately 1/4-inch shorter than the smooth shank nail. Current recommendations, however, are to use the twisted wire nail in the same length as the smooth shank common nail, but in slightly narrower gauges.

Much has been written in recent years on the subject of nail popping, and the question has been studied by laboratories in various parts of the world. It now appears to be generally agreed that nail popping is related both to the length of the nail and to the shrinkage of the wood into which the nail is driven. Whenever it is impossible to construct residences of thoroughly seasoned lumber it becomes highly desirable to use the shortest nail possible in locations where nail popping is likely to be a problem. Some of the helically threaded and annular ring nails develop tremendously increased withdrawal resistance and lend themselves to this use. Experiments carried out by the FPRB have shown that a 1 3/4-inch annular ring nail can develop, under certain conditions, over twice the withdrawal resistance of a 2 1/4-inch common nail.

Further, the nail popping of the two nails is roughly in proportion to their respective penetrations into the second piece of wood.

#### CONTRIBUTIONS OF THE NATIONAL RESEARCH COUNCIL

Mention has already been made of the close working relationship with the Division of Building Research of the National Research Council of Canada. The work of this Division, as the name implies, embraces research in all branches of building construction in Canada. Since wood is one of the principal components of residential construction in Canada, it is only natural that the engineers employed in this Division are often engaged in research problems involving wood. Conversely, FPRB engineers are often confronted with problems involving buildings. To avoid duplicating research which might be carried on by the two organizations in this overlapping area, a close liaison is maintained by the specialists concerned to ensure that the work is complementary and not conflicting or repetitive. One of the important co-operative projects which has been undertaken by the Division of Building Research and the FPRB has involved the design and verification of several types of trussed rafters in various spans and slopes for the use of Central Mortgage and Housing Corporation. Some of these trussed rafter designs have been developed by the Division of Building Research and others by the FPRB and the combined designs have been published by CMHC in one of their Builders' Bulletins. Any architect or house builder in Canada is free to use these CMHC-accepted designs in the construction of a house under the National Housing Act. While the design and verification



FPRB 2-600

Figure 5 — Test on sheet metal joist hangers nailed to joist and to supporting headers.



of wood trussed rafters does not appear at first sight to be an investigation of mechanical fastenings, it will soon become evident to anyone in this field that the fastenings are often the most critical aspect of the design.

Prior to the carrying out of this joint research project on nailed trussed rafters with plywood gussets, the Division of Building Research carried out a series of investigations into the strength of conventional joist and rafter construction. Several types of assemblies were investigated including rafters which run parallel to the ceiling joists and which are nailed to the ceiling joist at the point of overlap, and roof rafters which are not always parallel with the ceiling joists and which are supported on 2 x 4 plates which are nailed to the tops of the ceiling joists. It can be seen that a variety of assembly techniques can be employed depending on the design of the roof.

These investigations revealed, first of all, that the rafters themselves, when designed in accordance with the National Building Code of Canada, never failed when carrying loads equivalent to the design snow loads required by the Code. In every instance, it was found that the weak point in the assembly was the nailed connection between the rafter and the ceiling joist or plate. Typical joist and rafter assemblies tested by the Division of Building Research failed under uniform loads varying from 18 lb. per sq. ft. to about 100 lb. per sq. ft. This is a shocking variation if one considers that all the joist and rafter assemblies which were investigated had been, and were being, used in areas where the Code called for a design snow load of 50 lb. per sq. ft.

In attempting to find a possible explanation as to why roofs which fail at loads as low as 20 lb. per sq. ft. should give, or appear to have given, good service over many years in areas where the design snow loads can be as high as 50 lb. per sq. ft., one has to go back over the history of the development of house construction in the past several decades.

In the early days of house construction in Canada, the tendency was to build roofs with a fairly steep pitch, sometimes with angles in excess of 45° with the horizontal. Attics in those days were not ventilated and ceilings were not insulated. The snow which did not slide off the roof was frequently melted by heat lost from the interior of the house. Thus, the steeply pitched roof would collect smaller quantities of snow and the joint between the rafters and the ceiling joists would not be seriously stressed. The modern trend, however, is for the pitch of the roof to become flatter, thereby increasing the horizontal thrust at the connections between rafter and ceiling joist. At the same time, the trend has been to increase the insulation provided in the ceiling of the house and to ventilate the attic to prevent condensation in the winter. All of these factors tend to increase the snow load on the roof and to increase the

horizontal thrust at the nailed connection at the eaves, unless vertical support is provided at or near the ridge. Hence it is logical to expect that, if relatively few roofs have collapsed in the past, more roofs can be expected to collapse in the future unless something is done to improve the nailing at these vital connections. This matter has received careful consideration, not only by the Division of Building Research, but by the FPIB and other organizations. As a result, the number of nails required for fastening the roof rafters to the joists at the eaves has been quite substantially increased. The older codes made no mention of the nailing of the rafters to the supports, or else specified a nominal three nails for making this connection. Even when three nails were specified, it was frequently left to the imagination of the carpenter to decide what type of nail should be used and how it should be applied. Such questions are no longer being left to chance. Not only has the number of nails been increased two or three times in some instances, depending on the span and the slope of the rafters, but the length and method of fastening the nails have both been specified.

Mention has been made of the development of nailed plywood-gusset trussed rafters for use in NHA house construction in Canada and which have been developed by the Division of Building Research and the FPRB. While trussed rafters of this type have the advantage that small-scale builders can make use of these designs, they do not lend themselves to economical mass production as do trusses fabricated with metal truss plates. In recent years, many large Canadian builders have started to make use of trussed rafters assembled with metal truss plates, and several companies have been established in Canada both for manufacturing the plates and for manufacturing the finished trussed rafters for sale to builders. Metal truss plates present a special problem because, being a patented device in each instance and with many varieties and styles available, it is not feasible to set up safe load values per tooth or per square inch for each type of plate. It has been necessary, therefore, to require load-carrying tests on all trussed rafter designs incorporating metal truss plates which are proposed for acceptance by CMHC. To facilitate a standardized pattern of acceptance, the Division of Building Research, CMHC, and the FPRB have collaborated in setting up a set of performance criteria which must be met or exceeded by trussed rafters proposed for use in NHA housing. These performance criteria, which are relatively liberal by comparison with those in some other countries, are briefly as follows. When subjected to a uniformly-distributed load, equal to the design snow load for which the trusses are designed, plus a 10 lb. per sq. ft. uniformly-distributed load on the ceiling, the trussed rafter must not deflect more than  $1/360$  of the span after being loaded for a period of one hour. In addition, the trussed rafter must carry a uniformly-distributed load equal to twice the design snow load, plus the same 10 lb. per sq. ft. ceiling load for a period of 24 hours without failure. While these performance criteria are acknowledged to be much less severe than in some other countries, they assure a strength and a stiffness

in trussed rafters which is, generally, at least equal to the strength and stiffness of the best types of conventional joist and rafter construction which have proved to give generally satisfactory performance in practice over the years.

#### AN OUTLOOK FOR THE FUTURE

Engineers engaged in wood fastener research can expect in the future to be faced with a never-ending series of problems concerning the performance of mechanical fasteners in residential construction. As was stated previously, most of the houses built in Canada are constructed of wood frame construction. Developing a strong, efficient connector for wood construction has always been a problem. Inventive genius will continue to produce more and more new types of mechanical fastening, including special types of nails, staples, truss plates, and other devices. The FPRB and other organizations including the Division of Building Research, will continue to be presented with problems requiring experimental analysis. At the present time it appears that each new problem will be attacked by whatever method appears to be most suitable. It does not appear that Canadian research organizations will ever be in a position to carry out a gigantic research program which will provide, for all time, the numerical answers to all likely questions concerning the strength and stiffness of mechanical connectors in wood. Nevertheless, efforts will be continued to obtain more accurate design data on such questions as snow loads, and to develop better performance criteria for structural assemblies. This will greatly assist in the evaluation of mechanical fastenings as the need arises.