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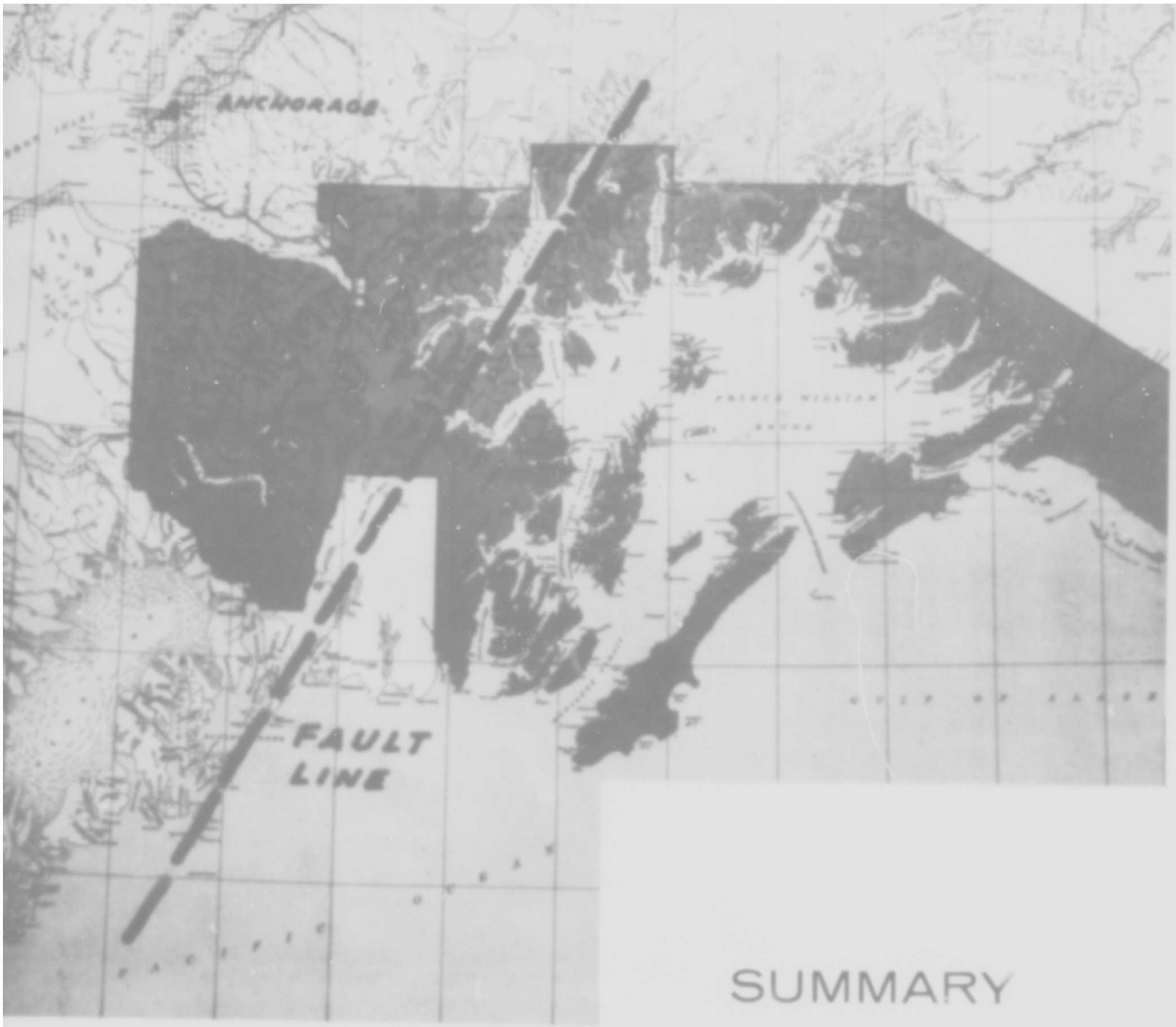
WOOD STRUCTURE PERFORMANCE IN AN EARTHQUAKE

IN ANCHORAGE, ALASKA

U. S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
FOREST PRODUCTS LABORATORY MADISON, WISCONSIN



ZM 126 415

Figure 1.--Anchorage, Alaska, in relation to fault line and the Prince William Sound area.

SUMMARY

Well-constructed light wood frame buildings for the most part resisted the shock forces of the earthquake that occurred in Alaska on Good Friday of 1964. This was not generally true of other types of construction. Because the majority of the homes in the Anchorage area were of wood frame construction, damages were usually superficial except in those areas where severe earth subsidence had occurred. There was some variation in the performance of the houses, based often on material choice, fastening methods, and construction details. Because the primary purpose of the survey was the investigation of wood frame structures, the majority of the descriptions cover such units. However, in the interest of providing information for development of better construction details for small buildings constructed of a combination of materials, illustrations and details of many types of failures are included.

WOOD STRUCTURE PERFORMANCE IN AN EARTHQUAKE[1]

IN ANCHORAGE, ALASKA MARCH 27, 1964

by

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and
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FOREST PRODUCTS LABORATORY[2] FOREST SERVICE

U. S. DEPARTMENT OF AGRICULTURE

INTRODUCTION

On Friday, March 27, 1964, an earthquake of intensity estimated at 8.6 on the Richter Scale occurred in the Prince William Sound area at 5:36 p.m. Anchorage time. It is stated that the epicenter was located at approximately 148° longitude and 61° latitude, which would put it some 80 miles southeast of Anchorage. The fault has been described as a line from the epicenter toward Kodiak Island (fig. 1). It is reported that the land west of the fault sank from 1 to several feet, while the land east of the fault was raised in comparable amounts. The earthquake damage was variable, from severe to minor in various localities throughout the Prince William Sound area.

Early reports and news photographs indicated severe property damage. However, details of the kind of structural failures and the types of buildings that suffered the greatest damage were generally lacking. Because of U.S. Forest Service interest in the performance of wood structures, the Division of Forest Products and Engineering Research requested the Forest Products Laboratory to conduct a survey of the damaged area. These are the observations made during that survey.

Severe damage resulted from tsunami (seismic sea wave) action to several Alaskan cities, including Seward, Kodiak, and Valdez. In these latter areas, the wave action had carried many or most of the damaged structures into the sea.

Observations to evaluate the effect of the earthquake on structures were, therefore, confined primarily to the Anchorage area. The shock in the

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[1] The authors' inspection was greatly facilitated by the excellent assistance from the personnel of the Forest Service Region 10 office, including W. H. Johnson, Regional Forester; Richard W. Wilke, Regional Engineer; Cecil A. Stowell, Assistant Regional Engineer; and Malcolm Greany, Photographer; and by J. F. Grant, Supervisor of the Chugach Forest, and John F. Mufich, Forest Engineer.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Figure 2.--Anchorage. The large cross-hatched area on the left is the Turnagain bluff housing area where damage to houses was caused by major earth slides.

Anchorage area was reportedly very severe over the entire city and lasted a period of several minutes. Therefore, building damage in varying amounts occurred throughout the city.

In general, it might be said that the major buildings were damaged because of the acceleration forces on the buildings and lack of frame action; damage to the smaller buildings and houses resulted primarily from foundation failures. It is reported that Anchorage is deep in an earthquake zone and that most of the city is built on a glacial outwash of sand and gravel up to 50 feet thick, which rests on 100-foot-thick beds of saturated Bootlegger Cove clay. When this soil was set in motion by the quake, destructive slides occurred that were responsible for severe damage in many areas.

The concentrated earthquake damage in Anchorage was confined to three major areas (fig. 2). In the Turnagain bluff area, the earth tended to crack, slide, and fold over toward Cook Inlet with resulting severe damage to 77 houses.

ZM 126 414

Figure 3.--Wood frame home in Turnagain bluff area. Earth subsidence destroyed a portion of the basement but caused little harm to house. Temporary bracing has been placed under the left portion.

ZM 126 419

Figure 5.--Fissure in earth (center, foreground) caused slight movement of floor slab and twisting of garage door. This home is near the Turnagain housing area where severe earth slides occurred.

There were massive slides in this area, and at the time of the inspection much of the remaining bluff area was in hazardous condition.

Other major areas of damage occurred in the central area of Anchorage, and resulted from a major subsidence of the earth known as a graben. In these areas, which varied from narrow cracks to those 300 or 400 feet in width, the structural damage was most often due to the slumping of the soil.

A similar type of failure occurred in the Government Hill area where the earth had subsided some 15 to 20 feet and resulted in the collapse of the Government Hill School and several houses in the area (fig. 2). In this area, however, very little damage to structures was noted outside of the major subsidence zone.

It was reported that 215 homes were destroyed in the Anchorage area and 157 commercial buildings were made unusable. The estimate of damage was approximately $200 million. At the time the examination was made, 1-1/2 weeks after the quake, undamaged homes and businesses were back in operation with gas, lights, and water facilities.

In general, it might be said that structural failures resulted from inability of the structure to act as a unit or because inadequate provisions were made for resistance to lateral loads. Well-constructed wood buildings usually came through the earthquake with a minimum of damage. Many steel and concrete buildings came through the earthquake very well, but many were severely damaged. Size and height of the building and the severity and duration of the shocks may have been important factors in the variation in damage to the many structures.

Figure 4.--Failure of a section of basement wall did not harm this two-story wood frame house.

ZM 126 416

Figure 6.--Inadequate fastening of wall to floor system caused some floor damage. Little racking of the house was apparent though one end had fallen into an earth fault.

ZM 126 421

ZM 126 422

Figure 7.--Although the porch is somewhat awry, this small wood frame house was rigid enough to span the hole caused by earth subsidence.

SMALL WOOD FRAME BUILDINGS

The greater portion of the time spent on examination and analysis of earthquake damage was concentrated on wood frame houses and apartments. It was felt that inspection of both sound and failed buildings would reveal factors relating to good performance, and result in improved construction details for wood structures.

Foundations

The majority of the wood frame houses in the earth subsidence areas and in adjacent areas contained basements, although both crawl space and slab construction were noted in homes and in

Figure 8.--Earth collapse caused failure of the concrete block foundation wall of this crawl space house. A portion of the top course of the block is still attached to the floor plate. The rigidity of the wood-framed walls prevented deflection and damage to the house proper. ZM 126 424

ZM 126 425

Figure 9.--This one-story office building constructed on a concrete slab was racked and badly damaged in an earth subsidence area, primarily because of slab failure. Wood roof decking and laminated beams are practically undamaged.

medium-size apartments. A number of houses remained in place, partially supported on relatively solid ground, even though portions of the masonry wall basement were destroyed when the earth dropped from under the house (figs. 3 and 4). However, the inherent rigidity of the exterior and interior walls of the wood frame houses was sufficient to prevent any significant deflection or

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Figure 10.--Although this wood house had been exposed to earth slides as well as shocks from the earthquake, only moderate damage to the structural frame was apparent. ZM 126 427

ZM 126 428

Figure 11.--Although tipped and dropped many feet, this wood frame house still retained its identity.

ZM 126 431

Figure 13.--Plywood sheathing over wood framing was responsible, in part, for the durability of this house.

damage. Most of the buildings under these conditions were to be moved to new locations.

Under conditions of earth subsidence, most concrete or masonry foundation walls or concrete slabs were destroyed even though the wood frame superstructure was often undamaged. In fringe areas, where homes were subjected only to shock and to lateral earth movement that caused fissures in the earth, some foundation damage occurred, especially to garage footings and slabs (fig. 5). Of the basements examined in these fringe areas, only minor cracking of masonry walls was noted that would not affect their structural utility.

Floor Systems

Wood frame floor systems performed well with relatively little damage even though basements or foundation walls had been destroyed. There were several instances, however, where wall-to-floor fastenings were insufficient and the floor had pulled away from the wood frame wall (fig. 6). Metal straps similar to those often used in hurricane areas or diagonal wood or plywood sheathing nailed to both floor and wall framing would probably have prevented this type of failure. The wood floor and wall systems were usually sufficiently strong to support the weight of the house even though most of the foundations had failed (fig. 7).

There were several instances where concrete block foundation walls had collapsed in the earth drop areas, leaving a row of blocks or a few blocks attached to the floor framing because of the wood plate-to-foundation anchor bolts (fig. 8). In this instance, the separation of floor and foundation was an advantage. If the bolts had been spaced closer together and extended down into the masonry wall a greater distance, it is possible that greater damage would have occurred to the house because of the suspended weight of the masonry.

Concrete slab floors were usually destroyed in the earth drop areas. Because frame walls were anchored to the slabs or to perimeter foundations, they too were generally racked or damaged (fig. 9).

Figure 12.--The rigidity of the wood framed wall is clearly evident in this three-story apartment building. ZM 126 429

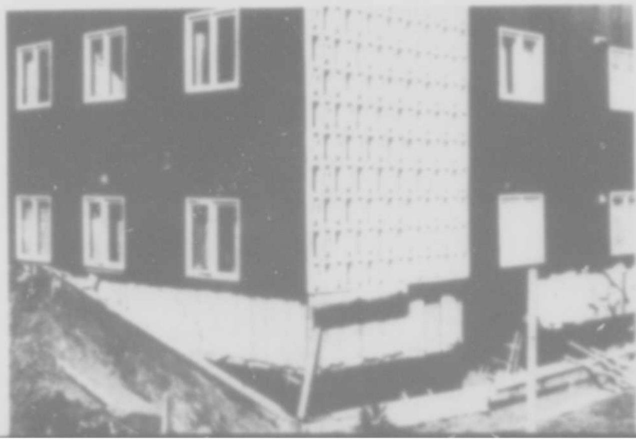
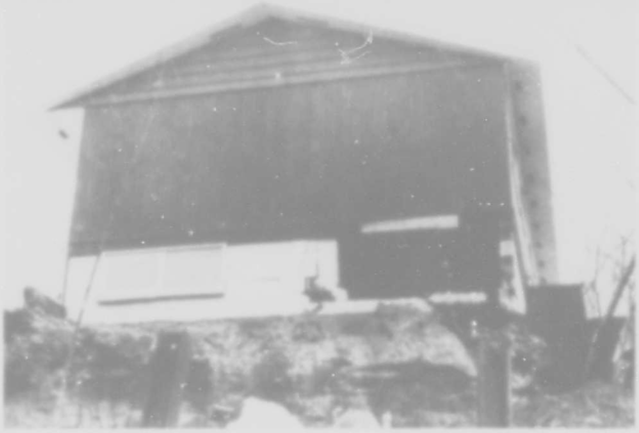


Figure 14.--The impact of the sudden earth subsidence was sufficient to cause shearing of the fiberboard sheathing. ZM 126 433

ZM 126 434

Figure 15.--Wood sheathing and siding over a wood framework, together with good nailing, provided strength and rigidity in this house.



ZM 126 433

Figure 17.--Partial collapse of the basement wall had little effect on the rigidity of this plywood-sided house.

Wood Frame Walls

Wood frame walls that were properly constructed resulted in an amazingly rigid unit with the capacity to resist shock and impact forces (figs. 10 and 11). Such construction involved braced frame wall, floor, and roof systems properly fastened together. Well-nailed sheathing and siding provided additional rigidity. The exterior walls are of the most important components of the structure, and the choice and use of materials, construction details, and fastening methods generally determine their performance (fig. 12). A conventional stud wall with diagonal sheathing, horizontal wood sheathing with let-in braces, or plywood sheathing provided the strength and rigidity necessary to resist the shocks of the earthquake as well as damage by earth slides.

Of the sheet materials commonly used for sheathing, plywood did an outstanding job in the houses examined (fig. 13). In the majority of cases, it was applied with the 4- by 8-foot sheets placed vertically, with perimeter nailing. Fiberboard sheathing in 25/32-inch thickness, when used properly, seemed to perform satisfactorily except where high stresses had caused shear failures between studs (fig. 14). However, not all fiberboard sheathing was applied properly with good nailing. Often 4- by 8-foot sheets were placed horizontally without edge nailing between studs. Some 2- by 8-foot fiberboard sheathing was also noted. Generally, failures of this type of sheathing consisted of nailhead pullthrough or shearing out at the nails due, in part, to inadequate nailing. These walls were usually racked beyond repair.

The use of horizontal wood sheathing, generally with let-in bracing, was quite common, especially in the older houses. This combination with wood siding of some type had provided more than sufficient rigidity and strength as indicated by houses which spanned holes or were supported only at the center (fig. 15). Interior wall covering of plaster or dry wall likely provided additional racking resistance.

The type of exterior covering evidently had some effect on the rigidity and strength of the

Figure 16.--Although this wood frame apartment building had dropped almost 6 feet, the plywood-faced panels helped to minimize damage. ZM 126 435

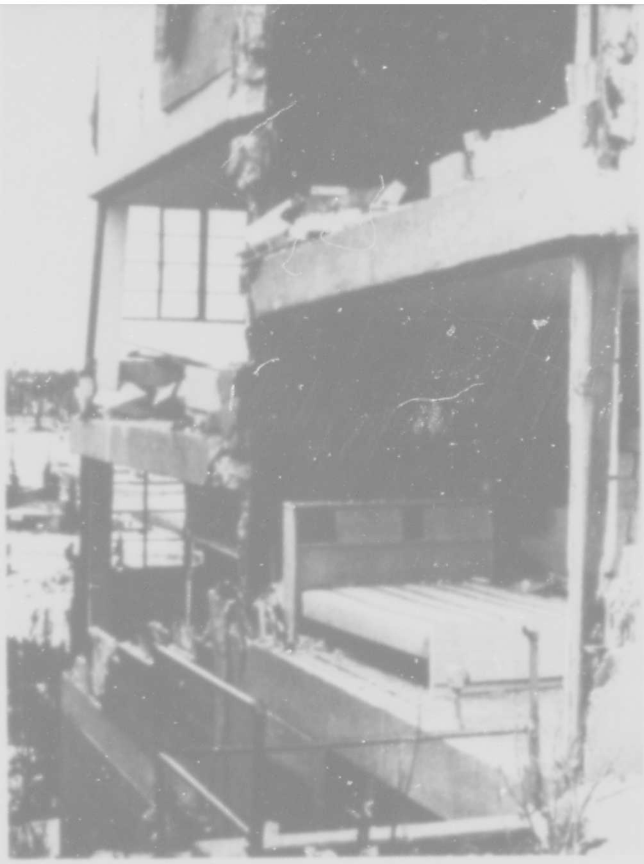
Figure 18.--Although the earth dropped under this house, the wood sheathing and stucco exterior provided a good shear wall. ZM 126 436

ZM 126 438

Figure 19.--The drop siding without use of sheathing did not provide enough rigidity to prevent damage to this house.

wall. Wood-sided walls performed well, as did panelized walls finished with plywood or paper-overlaid plywood (figs. 16 and 17). A number of houses, both old and new, with wood sheathing and a stucco (over wire lath) finish also appeared resistant to the forces of the earthquake and earth drops (fig. 18). Such finishes were also used on several wood-frame apartments with little or no evident damage. The use of a single covering material such as drop siding without benefit of sheathing did not supply sufficient strength (fig. 19). In

Figure 20.--The nonflexible facing of masonry failed but the more flexible wood wall framing remained undamaged. ZM 126 439



ZM 126 440

Figure 21.--This apartment house was finished with a facing of brick backed by concrete block. Corner windows provided little shear resistance to the walls.

another house, similarly covered, nails had pulled out at the corner studs, allowing major damage and failure of the wall because of excessive racking.

The failure of masonry veneer such as concrete block or brick was noted in a number of cases (figs. 20 and 21). In the wood-frame house (fig. 20), the rigid, brittle facings had fallen away, revealing the undisturbed wood frame wall and sheathing behind them. Even brick or other masonry veneer with the normal amount of metal ties to the wood

Figure 22.--Poor corner reinforcing is evident in this house with poured concrete walls damaged in an earth subsidence area. ZM 126 441

ZM 126 442

Figure 23. The narrow front walls of this double garage provided little resistance to racking stresses. Living area on upper floor is relatively undisturbed. Note temporary posts and bracing.

framing might not have resisted the shock forces without some damage.

There was evidence, in some of the more highly stressed houses such as those dropping or sinking into holes caused by earth failures in the Turnagain area, that improved fastening systems would be desirable for interior partitions intersecting exterior walls. Normally, these walls are fastened to exterior walls by nailing along the stud joining the wall and by the crossing top plate. The interior finish does little to tie the two walls together. These interior walls are important, as they serve to reduce the span of outside walls and act much as the partitions in a box to supply additional rigidity and strength. One poured concrete house failed in part because of poor corner reinforcing (fig. 22).

The racking resistance of a frame wall is, of course, partly dependent on the location of the openings. Corner windows or openings near corners did much to reduce the rigidity of the wall. One wood frame house contained a living area above a double garage. The narrow side and center

Figure 24.--This modern log house was in excellent condition although basement walls were damaged because of earth shifting. ZM 126 443

ZM 126 444

Figure 25.--Although the earth beneath it had rolled and slid, the log house remained relatively undamaged.

panels on each side of the garage door openings provided little racking strength (fig. 23). This was apparent by the failure of this section of the house.

Several log houses, new and old, were located in the earth drop areas. Beyond some minor damage, these structures appeared in excellent condition (figs. 24 and 25).

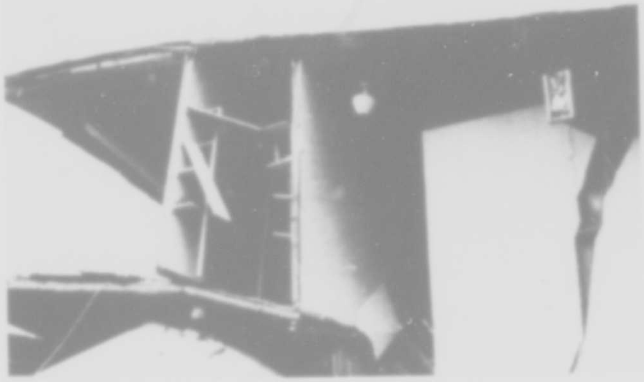
Roof Construction

Generally, in most wood frame construction, the roofs resisted damages by the earthquake very well even though subjected to severe earth drops (figs. 26 and 27). Most of the roofs on dwellings were of conventional construction with ceiling joists, rafters, and normal rafter ties. No wood trusses were noted. Several houses with low-pitch roofs were constructed with a ridge beam and wood decking or with ridge and intermediate purlin beams. In general, this type of roof construction had good resistance to damage. One

Figure 26.--Even though this wood frame house had dropped into an earth slide area, the roof remained rigid and essentially undamaged. ZM 126 446

ZM 126 447

Figure 27.--Both roof and wall rigidity prevented major damage to this house.



ZM 126 450

Figure 29.--The wood deck roof and floor and the wood partitions retained enough rigidity and strength to allow removal of stock in this hardware store even after it had fallen 10 feet or more into an earth subsidence area.

house constructed in this manner was located in the Turnagain area where severe earth subsidence and movement had occurred. However, the ridge beam, made up of three nail-laminated 2- by 12-inch members, failed by nail withdrawal and subsequent opening and failure at the ridge line (fig. 28). This type of beam should normally be a glue-laminated or solid beam or members should be securely bolted together.

Several office buildings, though not essentially wood frame structures, contained glue-laminated wood beam and wood deck roof construction. The beams and decking of these buildings, which had dropped into holes caused by earth failures, were in reasonably good condition. Because of failure of masonry or post and panel side walls, the alinement was slightly awry, but there was little evident damage to these wood components. Such roof and floor construction was used in a large hardware store in the downtown area (fig. 29). Failure of the earth had dropped the building 10 to 15 feet. While the decking and floor were tilted and deflected, they provided enough strength and rigidity to allow the entire hardware stock to be removed during the days immediately following the earthquake.

Miscellaneous

Masonry chimneys in areas outside the severe earth drop sections varied in damage from a few courses of brick to destruction of almost the entire chimney. However, there was no definite pattern, as a house with a badly damaged chimney might be located next to one with no visable damage. A number of prefabricated chimneys were noted, and from all appearances there was little damage due to shock forces alone.

Figure 28.--Nail-laminated ridge beam separated, causing roof failure of this attached garage.

ZM 126 448

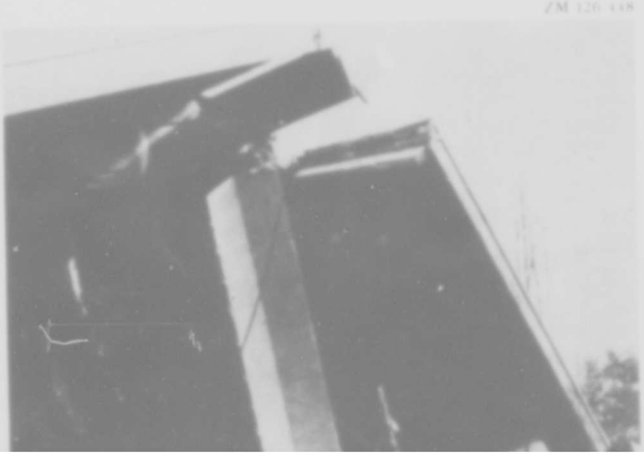


Figure 30.--Resistance to racking forces of the earthquake was lacking in this apartment building.

ZM 126 454

ZM 126 464

Figure 31.--The widely spaced columns of this school offered little resistance and failed at points of fixity at floors and roof line.

ZM 126 455

Figure 32.--The wall of the second floor offered some resistance to racking forces; not so the open first floor, which lacked enough reinforcement to resist lateral movement.

GENERAL COMMENTS

As previously outlined, the primary purpose of the survey in the Anchorage area was to obtain information on the performance of various types of wood structures and wood and wood-base materials. However, in addition to the notes and comments on wood frame construction, general information and photographs of other types of structures are included that may be of value to architects and builders.

Anchoring a wood plate to a masonry foundation wall is an important requirement in many areas where hurricane winds create lateral and uplift forces. However, in earthquake areas the purpose of an anchored plate may be somewhat different. There is need, perhaps, for some type of cushioning connection between basement wall and floor system to reduce or dampen shock forces normally transferred from the foundation wall to the house proper.

The need for good corner connections in exterior walls was apparent in most types of structures. In addition, openings at or near the corners reduced the racking resistance of the walls (fig. 30) and were partly responsible for damage to many buildings. Buildings with continuous openings or panels along the sides offered little resistance to racking forces (fig. 31).

Good nailing of sheathing and siding was important, as was the use of both these materials in exterior walls. Frame walls with siding alone did not provide sufficient rigidity and the lack of sheathing was often the cause of extensive damage. Because plywood and wood sheathing offered greater resistance to lateral movement of the nails than the less dense fiberboards which were used, performance of the plywood and sheathing was generally much better. The better lateral resistance resulted from more effectiveness of the nail couples. Plywood sheets, 4 by 8 feet or larger, placed vertically to allow for perimeter nailing provided excellent resistance to racking. It is felt that 1- by 6-inch or larger let-in bracing or better nailing would improve the performance of a wall sheathed with fiberboard or similar materials having lower densities than wood.

In normal wood frame construction, it appeared that nail assembly of the various wood parts offered adequate stiffness but allowed some small deflection sufficient to absorb and cushion shock forces and prevent major damage. This was not true of rigid mortar joints in masonry walls where only a slight movement would usually initiate failure.

Any connections or fastening methods that aid in developing a wood structure to act as a unit will result in greater resistance to earthquake damage. Thus, in low-pitch roofs where ties between opposite walls are partially dependent on the roof

ZM 126 465

Figure 33.--The reinforced spandrel panels over the windows failed in shear. Shear failures at each floor line are also visible.

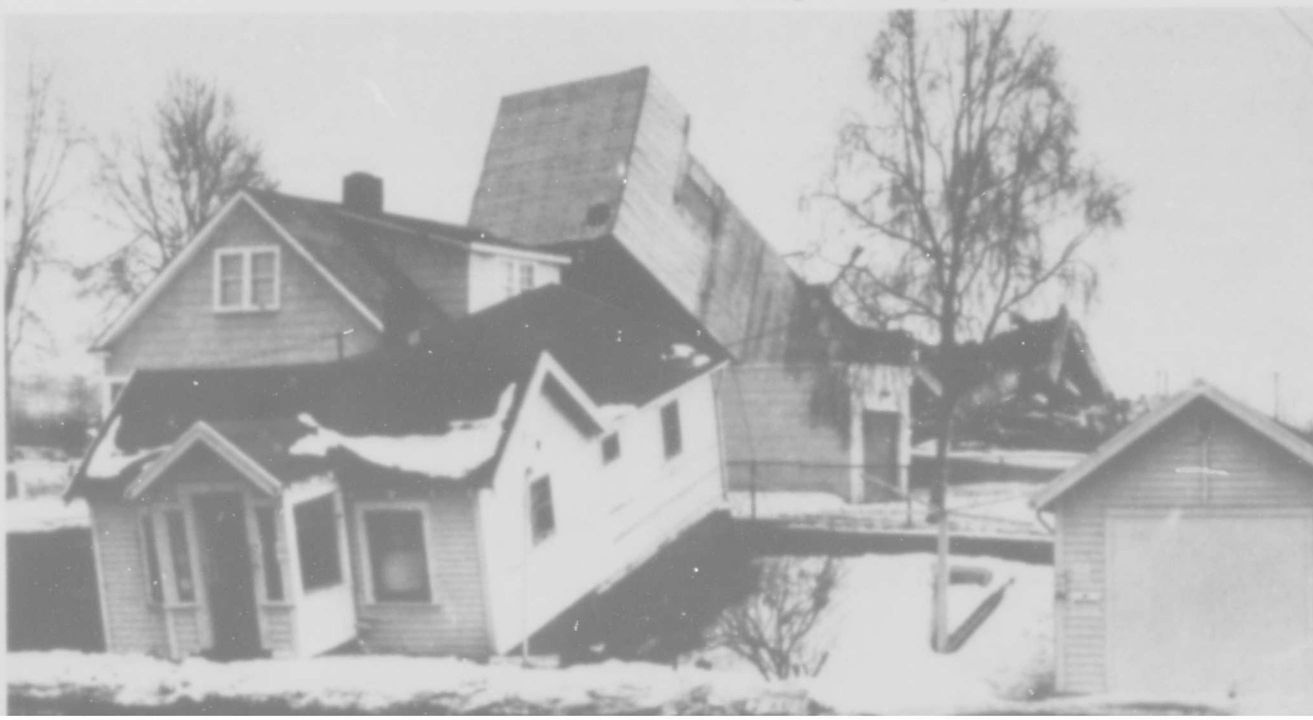
sheathing or decking, it is important that adequate connections be used at the ridge beam. This also applies to connections between the wall and floor systems. Diagonal sheathing, the extension of plywood sheathing over the header or band joists of the wood floor framing, or metal strapping, together with good nailing, are required to provide adequate ties between the floor, wall, and roof systems.

Glue-laminated wood beams in combination with wood decking performed well even in those buildings which were partially destroyed because of failure of other materials. A wider use of this and similar construction, including perhaps the use of more wood frame systems, could well be adapted to modern designs of small offices and other commercial buildings.

Buildings in earthquake areas should be designed so that all exterior faces have sufficient diagonal reinforcing to resist lateral movement. Several new two-story commercial buildings were designed with masonry end walls and long open or paneled sides which offered little or no resistance to racking stresses (fig. 32). Failure of the end walls because of little or no longitudinal resistance to racking had caused severe damage to the buildings. In two 14-story reinforced concrete apartment buildings, the shear forces damaged the spandrel panels over window openings (fig. 33) as the buildings swayed.

The construction of a resilient structural framework with covering materials flexible enough to withstand the lateral forces and deflections is difficult but necessary for earthquake-resistant structures. Such construction is found in the wood frame house (fig. 34).

Figure 34.--The small frame house and garage in the foreground suffered only minor damage though being dropped into an earth slide area, but the shock destroyed the lift-slab reinforced concrete building in the background. ZM 126 458



CONCLUSIONS

Apparently the long period of seismic vibrations together with the long duration of the shock was in part responsible for the severe damage to many structures. Thus, it is likely costly to design a large multistoried building which would be entirely free of damage after being subjected to forces such as produced by this 1964 Alaska earthquake. However, damage could be reduced so that the structure is repairable if more consideration is given to the adoption of designs and the selection of materials more resistant to such forces. Wood and wood products appeared to be one of the best of these.

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