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PROJECT 31.1

DAMAGE TO CONVENTIONAL AND SPECIAL TYPES OF RESIDENCES EXPOSED TO NUCLEAR EFFECTS

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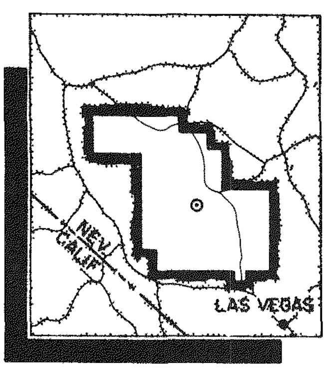

CIVIL EFFECTS TEST GROUP

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Report to the Test Director

DAMAGE TO CONVENTIONAL AND SPECIAL TYPES OF RESIDENCES EXPOSED TO NUCLEAR EFFECTS

By

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Director
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Office of Civil and Defense Mobilization
Washington, D. C.

and

Federal Housing Administration
Washington, D. C.

and

Housing and Home Finance Agency
Washington, D. C.

March 1961

ABSTRACT

In Project 31.1, 10 residential structures of wood, brick, lightweight reinforced-concrete block, and lightweight precast concrete slabs were exposed in pairs to the effects of a nuclear device (Apple II) of approximately 30 kt yield, detonated atop a 500-ft tower.

Two houses were two-story and basement structures of wood-frame construction. These houses were redesigned and strengthened on the basis of studies of the findings on similar houses exposed to the effects of a nuclear device in 1953. One of the houses (31.1-b1) was exposed at approximately 4 psi overpressure; the other (31.1-b2), at approximately 2.6 psi overpressure.

Two houses were two-story and basement structures of brick and cinder-block exterior walls, cinder-block basement walls, and wood-frame floors, partitions, and roof. One (31.1-a1) was exposed at approximately 5.1 psi overpressure; the other (31.1-a2), at approximately 1.7 psi overpressure. The size and layout of these houses were similar to the strengthened frame houses, but they were of conventional construction.

Two houses were one-story wood-frame rambler type houses; one (31.1-c1) was exposed at approximately 5.1 psi overpressure; the other (31.1-c2), at approximately 1.7 psi overpressure.

Two houses were built of reinforced lightweight concrete blocks with precast lightweight concrete roof slabs. One (31.1-f1) was exposed at approximately 5.1 psi overpressure; the other (31.1-f2), at approximately 1.7 psi overpressure.

The final two houses were one-story structures built of precast lightweight concrete wall, partition, and roof panels. One (31.1-e1) was exposed at approximately 5.1 psi overpressure; the other (31.1-e2), at approximately 1.7 psi overpressure.

Two houses of each type were tested, one house being located at an anticipated overpressure at which collapse or major damage might be expected and the other house being located at an anticipated overpressure at which damage without collapse might be expected.

The aboveground portion of the two-story brick and cinder-block house (31.1-a1) located 4700 ft from Ground Zero (GZ) was almost completely destroyed; the first-floor system was partially collapsed into the basement. None of the exterior walls remained standing, and the structure as a whole was beyond repair, even for emergency shelter from the elements.

The one-story frame rambler house (3.1.1-c1) located near the two-story brick dwelling 4700 ft from GZ was likewise àlmost completely destroyed. Only the reinforced-concrete bathroom shelter remained intact.

The one-story reinforced lightweight concrete-block house (31.1-f1) and the one-story precast lightweight concrete house (31.1-e1) suffered only minor structural damage. These houses were also located 4700 ft from GZ. With the replacement of doors and window sashes, both houses could be made habitable.

At 5500 ft from GZ the two-story redesigned frame house (31.1-b1) suffered severe damage and would not be suitable for occupancy without extensive and economically inadvisable major repairs.

At 7800 ft from GZ the two-story redesigned frame house (31.1-b2) suffered relatively heavy damage. The condition of the house was such that it could be made available for emergency shelter from the elements by shoring and not too extensive repairs.

The two-story brick and cinder-block house (31.1-a2) located 10,500 ft from GZ suffered considerable damage to the roof and second-floor ceiling, with minor damage to walls and floors. The masonry appeared to suffer little or no damage, although there was considerable damage to window sashes and doors. At a reasonable cost this house could be made suitable for emergency housing.

The one-story precast lightweight aggregate concrete house (31.1-e2) and the one-story reinforced masonry block house (31.1-f2), both located 10,500 ft from GZ, suffered relatively minor damage. Only minor repairs would be required to make these dwellings suitable for reoccupancy.

The one-story frame rambler house (31.1-c2) located 10,500 ft from GZ suffered relatively heavy damage, but nevertheless could be restored to condition suitable for occupancy at moderate costs.

Out of the 10 houses included in the test, the condition of 7 was such that they could be made habitable for emergency occupancy by shoring and repairs. In practically all the houses the windows and exterior doors were destroyed. In all except the two collapsed houses, the greatest danger to the occupants would appear to have been from missiles of glass, Venetian blinds, furniture, etc.

ACKNOWLEDGMENTS

Four of the test residential structures, two one-story houses built of expanded shale-aggregate precast lightweight reinforced-concrete wall and roof sections, and two one-story houses built of reinforced expanded shale-aggregate masonry block with precast lightweight concrete roof sections, were contributed jointly by the following companies: Basalt Rock Co., Napa, Calif.; Rocklite Products, Ventura, Calif.; Texas Industries, Dallas, Tex.; Buildex, Inc., Ottawa, Kan.; and Light Aggregates, Rapid City, S.D.

Participating with the Federal Civil Defense Administration in the tests of the houses were the Housing and Home Finance Agency and the Federal Housing Administration.

Assisting the author materially in evaluating damage to the structures were the Assistant Project Officer, Eugene F. Henry, representing the five above-listed companies; and Project Consultants William A. Russell, representing the Federal Housing Administration; Bernis E. Brazier, representing American Institute of Architects; and Richard G. Kimbell, representing National Lumber Manufacturers Association.

The services of the author, Philip A. Randall, as Project Officer, were made available by the Housing and Home Finance Agency.

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ILLUSTRATIONS (Continued)

Chapter 1

INTRODUCTION

1.1 OBJECTIVES

On May 5, 1955, at the Nevada Test Site of the Atomic Energy Commission, 10 residential structures were exposed to the explosion of a nuclear device (Apple II) of approximately 30-kt yield, detonated atop a 500-ft tower, to test their behavior and resistance to nuclear weapons effects and to obtain data that will contribute to the development of improved protective designs. From a determination of the behavior of these structures under blast, thermal, and nuclear radiation effects, it should be possible to determine the best steps to be taken for the protection of families living in such structures and to obtain necessary additional data on the strengths of the structures as a whole and possible weaknesses in component parts.

Project 31.1 was concerned primarily with blast and radiation effects on residential structures, and precautions were taken to avoid ignition of the structures by the thermal energy of the explosion.

Data obtained are expected to be useful also in the development of methods for strengthening the structures within limits of practical economy, and in providing information on the possible use of the structures for housing without major repairs following a nuclear event.

1.2 BACKGROUND

On March 17, 1953, two typical American houses of wood-frame construction were subjected to the release of energy from a 15-kt device (Operation Upshot-Knothole Report WT-792). The point of energy release was 300 ft above the ground. In addition to determining the gross effects of blast and thermal radiation from a nuclear device upon a typical American home, one of the primary purposes of the tests on these structures was to determine the adequacy of simple wood basement family shelters.

House No. 1 in this test was located 3500 ft from GZ and was subjected to an estimated overpressure of approximately 5.0 pounds per square inch (psi) or 720 pounds per square foot (psf). The house collapsed and was 90 to 95 per cent destroyed but did not completely disintegrate; it did not go down into the basement in a single compacted pile of rubble. Results indicated that the basement shelters were adequate for security from the resulting debris. There was no free-flaming or burning of the building as a result of thermal radiation; however, the front of the structure was deeply scorched. No live utilities were included in the houses being tested.

Parts of the basement walls were the only portion of the structure that could have been used again. The first story was completely demolished, and the second story, which was badly damaged, dropped on the first-floor debris. The roof was blown into several sections, the rear section being blown into the back yard. The upper half of the front part of the roof was turned upside down in the front yard; the lower half landed at some distance from the house to the rear. The gable end walls were blown apart and outward. The chimney was broken into several large masses and landed outward from the house at about a 45-deg angle to the rear.

The basement walls suffered some damage above grade, mostly in the rear. The front basement wall was pushed in slightly; it had not cracked except near the ends. The first-floor wood girders were pushed back, and the supporting pipe columns were inclined to the rear.

House No. 2 was located 7500 ft from GZ and was subjected to an overpressure of approximately 1.7 psi or 245 psf. The house remained standing but sustained considerable structural damage. It did not collapse, however, and could have been made available for reoccupancy under emergency conditions by simple shoring and reinforcement measures and closure of wall and roof openings.

The most apparent damage to this structure was the destruction of doors and windows, including sashes and frames. The front door disintegrated into its component parts, and the doorknobs and lock set were found halfway up the stairs to the second floor. The dining room-kitchen door also disintegrated, and one part of it was hurled into the plaster of the rear kitchen wall.

Principal damage to the first-floor construction consisted of broken joists. Most of the breakage originated at knots in the lower edges of the timbers. Some studs in the front wall of the house were cracked.

The second-floor construction suffered no apparent damage, but the plaster and windows of the second story were severely damaged. Roof damage consisted mainly of broken rafters in the front section. All rafters on the front side except one were split or broken. The roof was sprung slightly at the ridge. No rafters were broken on the back side of the roof.

On the GZ side the rafter ends were displaced from the wall plate, and the ridge ends of the rafters were moved, leaving an opening at the roof peak.

The basement showed no damage except to windows and the basement door and frame. With windows and door openings covered and minor shoring and reinforcement measures, the house could have been made habitable, under emergency conditions; but restoration of the house to its original condition would have been economically infeasible.

Many significant phenomena were demonstrated by the 1953 test and the results of study were incorporated in the redesigned two-story frame houses included in this 1955 test series.

Chapter 2

EXPERIMENT DESIGN

Five pairs of houses, ten in all, were included in the 1955 test series. The houses were exposed in pairs; one house of each pair was placed at an overpressure range where collapse or major damage might be expected, and the duplicate house was placed at an overpressure range where damage without collapse might be expected (Fig. 2.1).

2.1 TWO-STORY BRICK HOUSES (31.1-a1 AND 31.1-a2)

One pair consisted of two-story and basement center-hall wall-bearing houses with 8-in. masonry walls, consisting of an outer wythe of brick and a back-up wythe of cinder block. The basement foundation walls were 12-in. cinder block. The 2 by 8 in. first-floor joists had square-cut ends bearing on the inner 4 in. of the basement foundation wall. The 2 by 8 in. second-floor joists had an angular fire-cut end with 4 in. bearing on the cinder-block wythe. The gable roof was of typical wood-frame construction, with 2 by 6 in. rafters, 2 by 6 in. ceiling joists, and 2 by 6 in. rafter ties every third rafter. One house (31.1-a1) was located 4700 ft from GZ at an estimated overpressure of approximately 5.0 psi (720 psf); the other house (31.1-a2) was located 10,500 ft from GZ at an estimated overpressure of approximately 1.7 psi (245 psf). These houses were similar in size and layout to the two-story frame houses exposed in the current tests and in the 1953 tests, but the construction generally was conventional, no attempt having been made to strengthen the houses through special design (see Figs. 2.2 to 2.6).

2.2 ONE-STORY FRAME RAMBLER HOUSES (31.1-c1 AND 31.1-c2)

A second pair of houses was a one-story wood-frame rambler type, painted yellow, built on a poured-in-place concrete slab at grade. These houses were of conventional design, except that the bathroom was designed as an aboveground shelter with 8-in.-thick reinforced-concrete walls and ceiling. The wall reinforcing extended into the reinforced floor slab at grade, which was thickened to 12 in. under the bathroom. The bathroom door and window were equipped with a heavy wood blast-resistant door and window shutter. One house (31.1-c1) was located 4700 ft from GZ, at an overpressure of approximately 5.0 psi (720 psf); the other house (31.1-c2) was located 10,500 ft from GZ at an overpressure of 1.7 psi (245 psf) (see Figs. 2.7 to 2.10).

2.3 ONE-STORY PRECAST CONCRETE HOUSES (31.1-e1 AND 31.1-e2)

Another pair of houses consisted of single-story houses made of 6-in.-thick precast lightweight expanded shale-aggregate reinforced-concrete wall and partition panels, joined by welding matching steel lugs. Similar 6-in.-thick reinforced-concrete roof panels, 31 ft 6 in. long and varying in width from 4 to 8 ft, were anchored to the walls by special countersunk and grouted connectors to the wall steel. The precast walls were supported on concrete piers, and the reinforced-concrete floor slab, poured in place on a tamped fill, was anchored securely to the wall panels by means of a perimeter reinforcing rod held by hook bolts screwed into inserts in the wall panels. The house had an attached garage; the entire structure was painted white. One house (31.1-e1) was located 4700 ft from GZ at an expected overpressure of approximately 5.0 psi (720 psf); the other house (31.1-e2) was located 10,500 ft from GZ at an expected overpressure of approximately 1.7 psi (245 psf) (see Figs. 2.10 to 2.17).

2.4 ONE-STORY CONCRETE-BLOCK HOUSES (31.1-f1 AND 31.1-f2)

The fourth pair of houses consisted of one-story houses built of reinforced lightweight aggregate concrete blocks with reinforced lightweight aggregate precast concrete roof panels upon a poured-in-place reinforced-concrete floor slab thickened at the edges to form a combination footing and beam section under the exterior walls and also for the interior partitions. The walls and partitions were constructed of 8 by 8 by 16 in. hollow lightweight expanded shale-aggregate concrete blocks. Poured concrete studs, reinforced with ½-in.-diameter steel reinforcing rods, were installed at the corners, at both sides of all openings, and along the walls at a maximum spacing of 32 in. on centers between openings. These studs were formed by filling the aligned hollow cells in the concrete block. Lintel blocks served as forms for reinforced-concrete bond beams at the top course under the roof slab, at one intermediate course, and for lintels over all openings. The roofs of these one-story houses consisted of 6-in. precast lightweight expanded shale-aggregate reinforced-concrete slabs similar in size and design to those installed on the roof of the precast concrete panel house. These roof slabs were anchored to the concrete studs by ⅝-in.-diameter hook bolts. These hook bolts extended into a conical opening in the roof slabs which was grouted with concrete after a cap was secured onto the end of the bolt. The roof slabs were also provided with welding lugs for joining one slab to the other. One house (31.1-f1) was located 4700 ft from GZ at an overpressure of approximately 5.0 psi (720 psf); the other house (31.1-f2) was located 10,500 ft from GZ at an overpressure of approximately 1.7 psi (245 psf) (see Figs. 2.18 to 2.22).

2.5 TWO-STORY FRAME HOUSES (31.1-b1 and 31.1-b2)

The fifth pair of houses consisted of two-story and basement center-hall wood-frame houses, painted white, with reinforced-concrete basement foundation walls. One house (31.1-b1) was located 5500 ft from GZ at an expected overpressure of approximately 4.0 psi (576 psf); the other house (31.1-b2) was located 7800 ft from GZ at an expected overpressure of approximately 2.5 psi (360 psf). These houses were similar in size and layout to the houses tested in the 1953 series but were redesigned on the basis of the findings of that test to strengthen the structure so far as possible within an increase of approximately 10 per cent in the building cost (see Figs. 2.23 to 2.29).

In the 1953 experiment the test house at 3500 ft from GZ was moved from its foundation by the blast owing to failure of the connections between the wood sill plate on the exterior walls and the cinder concrete-block foundation walls. In the strengthened design the foundation walls were built of 8-in.-thick reinforced concrete with a 4 by 8 in. wood sill plate anchored to the foundation wall with ⅝ by 24 in. bolts on 2-ft centers in lieu of a 2 by 8 in. sill plate anchored to the cinder-block foundation walls with ½ by 16 in. bolts on 5-ft centers. In the basement, reinforced-concrete shear walls, forming the sides of the basement bomb shelter and the staircase, replaced the pipe columns that had been tipped backward by the blast in the previous test house.

There was an increase in the size and a strengthening of the connections of the first-floor joists, which in the 1953 test gave way under the pressure that carried in the windows and doors and bore down on the first floor over the basement. First-floor joists were increased from 2 by 8 in. to 2 by 10 in., and, in lieu of 1 by 3 in. cross-bridging at the mid-point of the span, the first and last two joist bays were braced every 16 in. with 2 by 10 in. solid bridging and the intermediate joist bays were bridged at the mid-point of the span with solid 2 by 10 in. blocking. Trimmer joists on either side of the fireplace were doubled, and metal joist hangers were installed to carry the tail-joist framing into the double header at the hearth to overcome a weakness that developed in the 1953 test. In the 1953 test house located at 7500 ft, the ends of the tail joists were only nailed to the header and, as a result of pressure downward, dropped several inches and pulled away from the header leaving the nails in the subfloor.

The second-floor framing was strengthened by the installation of solid bridging every 16 in. in the first and last joist bays, the intermediate joist bays being braced by the use of conventional 1 by 3 in. cross-bridging. In addition, $^5/_8$ in. round wrought-iron framing rods were installed on 48-in. centers in the first and last joist bay, anchoring the joists to the exterior-wall framing.

The second-floor ceiling joists were increased in size from 2 by 6 in. to 2 by 8 in., and metal joist hangers were installed to support all ceiling joists framing into the center beam support. In addition, wrought-iron strap anchors were installed over the beam to the lower edge of each abutting ceiling joist to strengthen this connection. Roof rafters, which in the 1953 test house had failed in the front slope of the roof, were increased in size from 2 by 6 in. to 2 by 10 in.

Exterior-wall construction was strengthened by the use of 2 by 6 in. studs extending from sill line atop foundations to the underside of the plate, so-called "balloon framing," in lieu of 2 by 4 in. studs, i.e., platform framing, used in the 1953 test house. Plywood wall and ceiling covering was substituted for the gypsum lath and plaster that was almost completely destroyed in the 1953 test.

The window frames were firmly secured in the wall openings. (In the 1953 test the frames were lightly nailed, and they were blown in.) In general, there was superior nailing of all the framing members and the sheathing, siding, subflooring, flooring, etc., using special grooved nails with greater holding power. (See Appendix A for the nailing schedule.)

2.6 INSTRUMENTATION

The results described in this report are based upon visual inspection. Still and motion-picture photography provided by Project 39.4 were utilized to further evaluate the effects of blast and heat. Pressure vs. time and total thermal energy instrumentation, installed under Projects 39.2 and 39.3, respectively (Reports WT-1192 and 1187), provided these data for use in more detailed analyses of results.

Film dosimeters were installed in the basement, on the first and second floors of the two-story houses, and on the first floor of the one-story houses to record nuclear radiation dosages. Badges located in the basements were suspended from the first-floor joists in three horizontal layers, one approximately 6 in. below the joists, one approximately 12 in. above the floor, and one midway between the top and bottom layers (see Fig. 2.31). On the first and second floors of each of the houses, film dosimeters were attached to the walls of all rooms in a horizontal layer about 5 ft above the floor (see Fig. 2.32).

Approximately 180 dosimeters were installed in each basement; approximately 50 in the upper floors of each of the two-story houses; 27 to 40 in the one-story rambler houses, depending upon location of the rambler from GZ, the nearer houses having a heavier concentration of dosimeters; 20 to 32 in the precast concrete houses; and 16 to 22 in the reinforced-masonry houses. The film dosimeters were supplied by Project 39.1, who also analyzed the results.

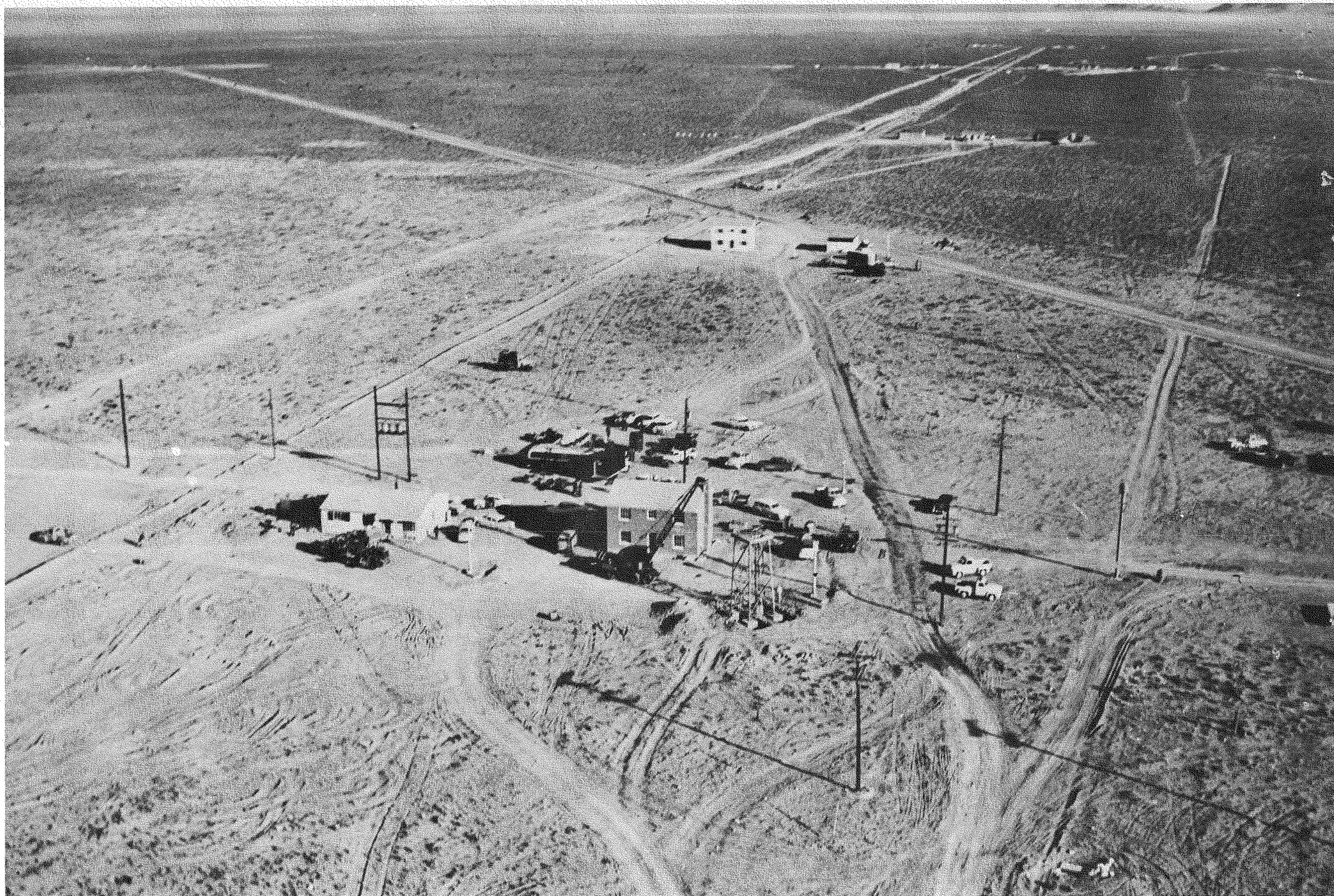


Fig. 2.1—Main FCDA test line, preshot, looking from GZ.

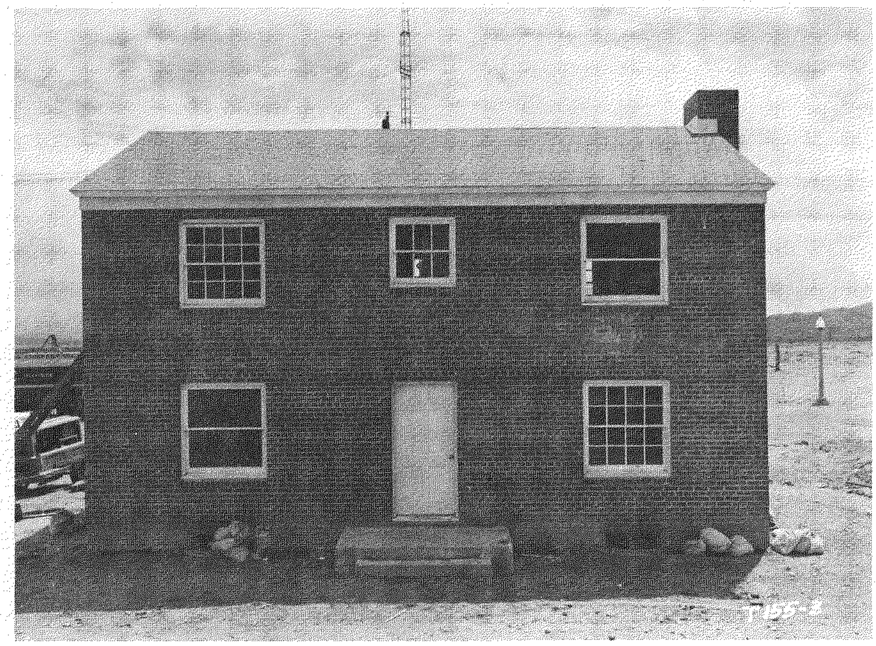


Fig 2.2—Two-story brick house (31.1-a1) at 4700 ft, preshot.

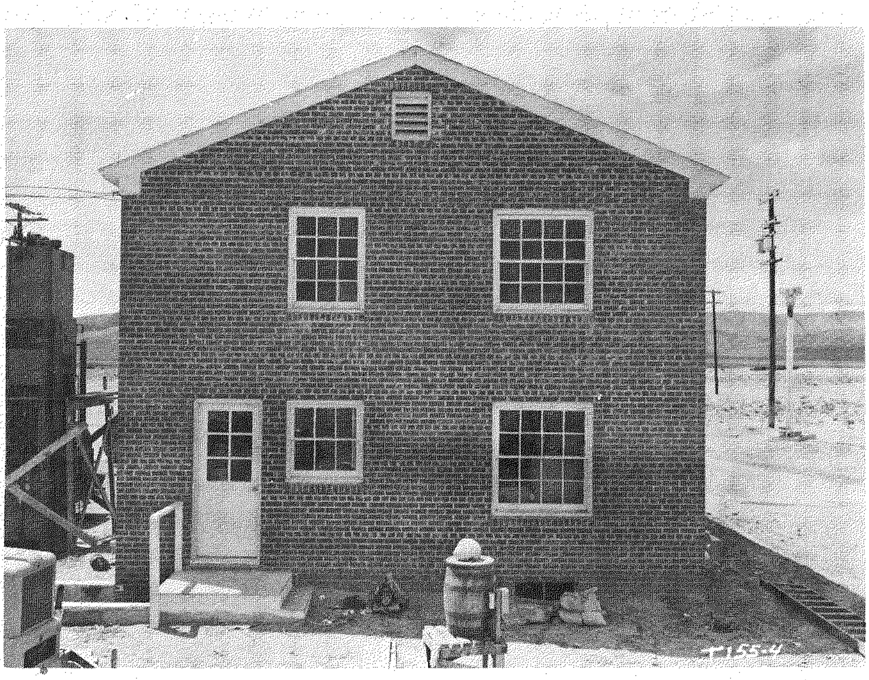


Fig. 2.3—Two-story brick house (31.1-a1) at 4700 ft, preshot.

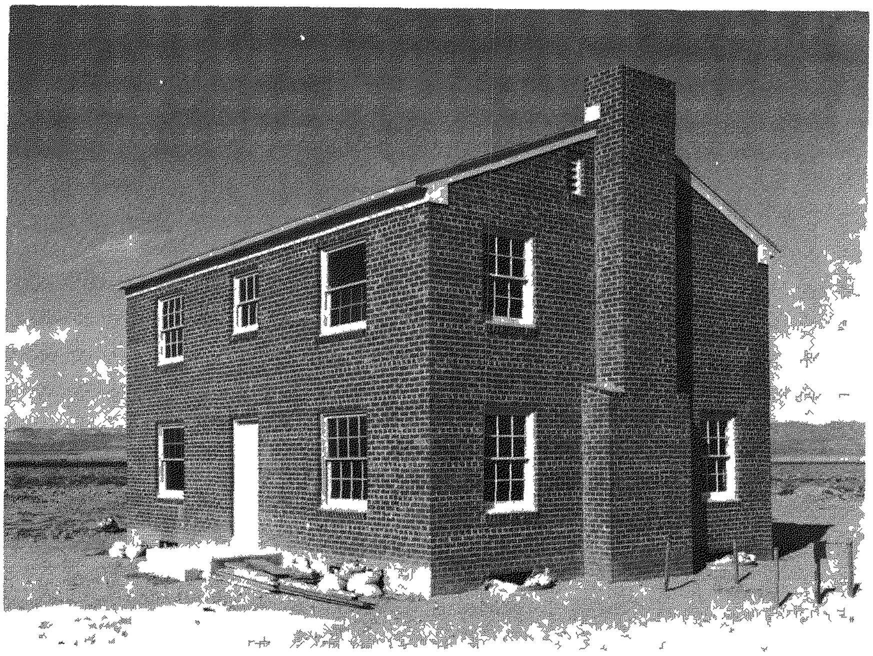


Fig. 2.4—Two-story brick house (31.1-a2) at 10,500 ft, preshot.

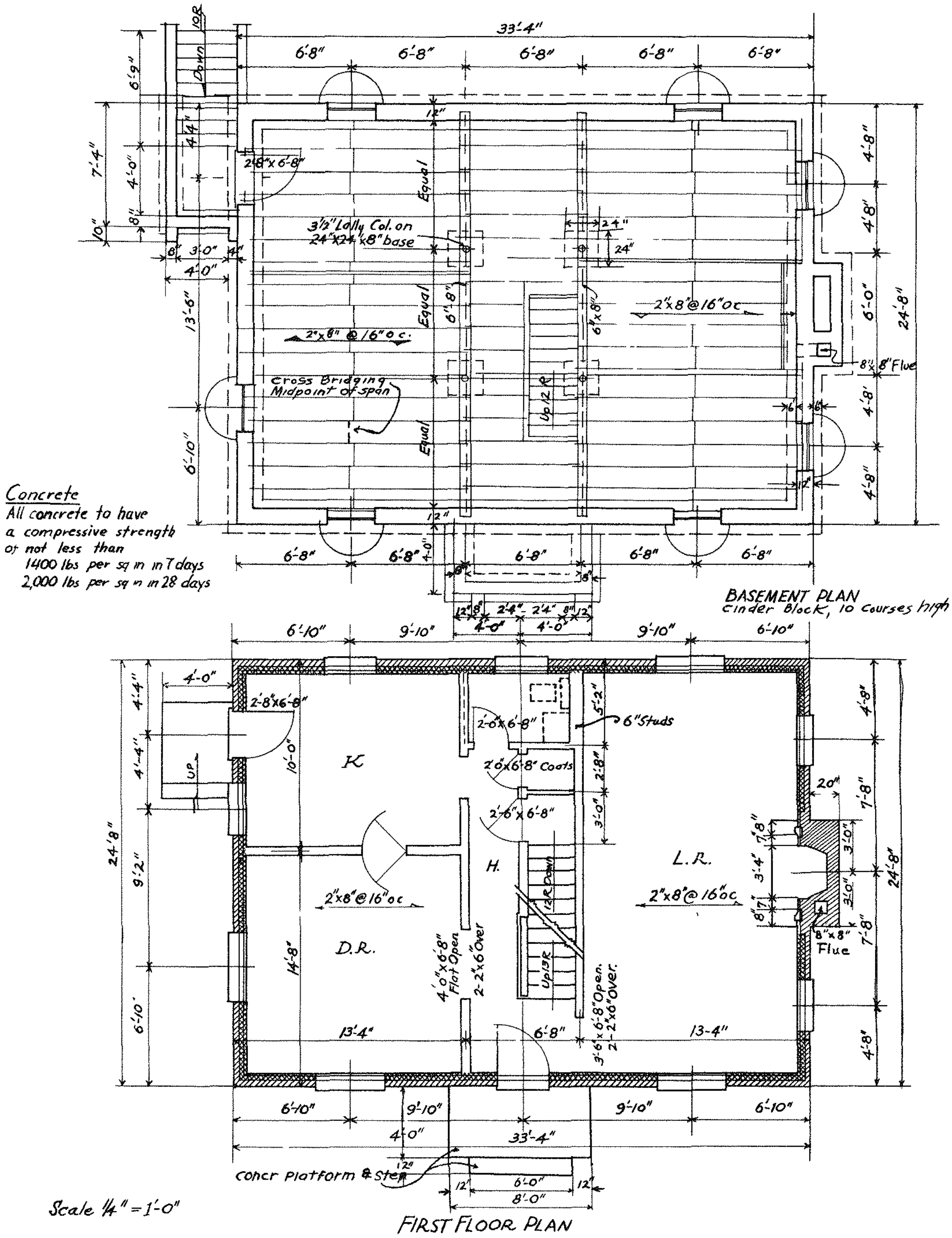


Fig. 2.5—Two-story brick and cinder-block house, first floor and basement (31.1-a1 and 31.1-a2).

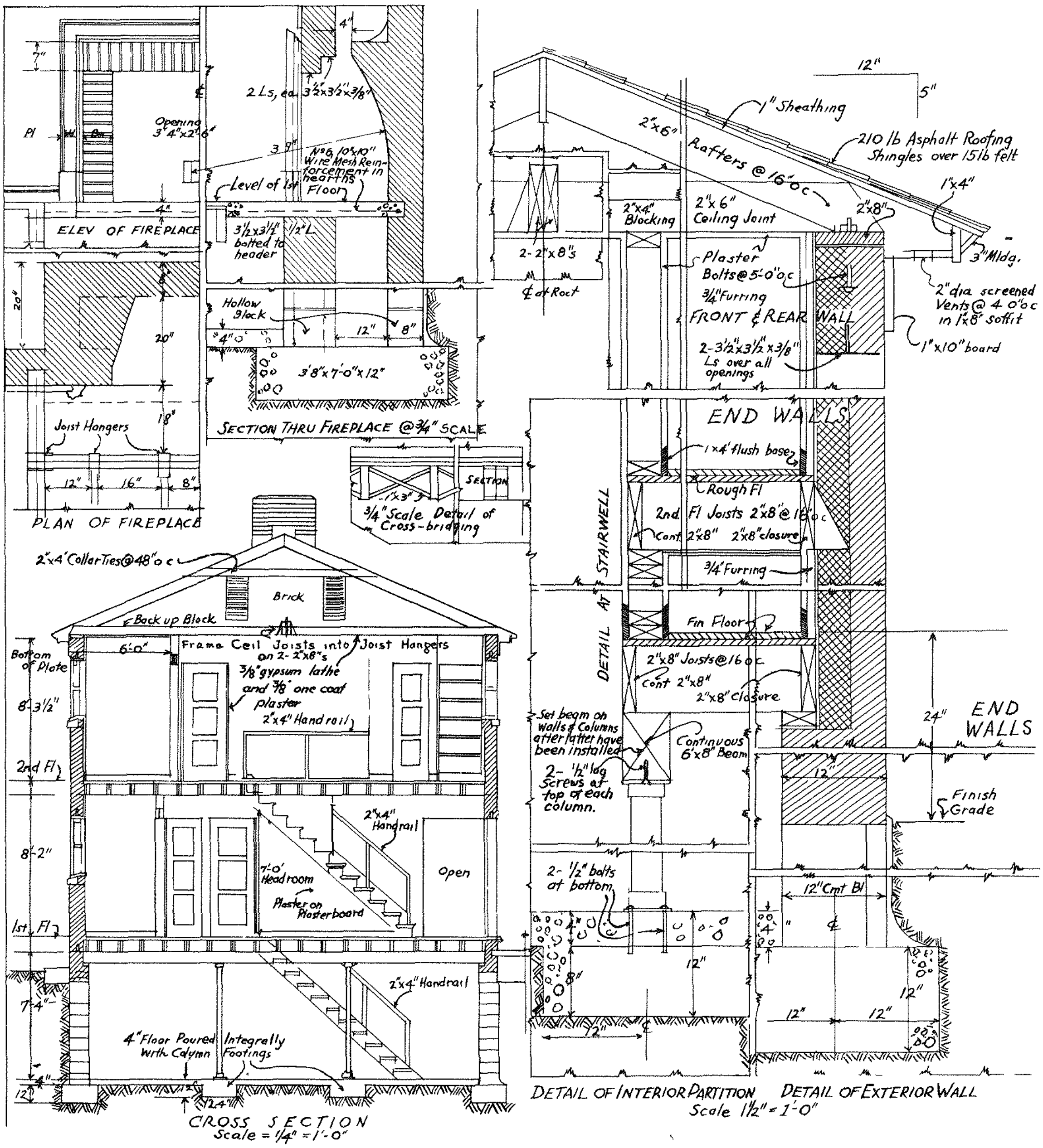


Fig. 2.6—Two-story brick and cinder-block house, sections and detail (31.1-a1 and 31.1-a2).

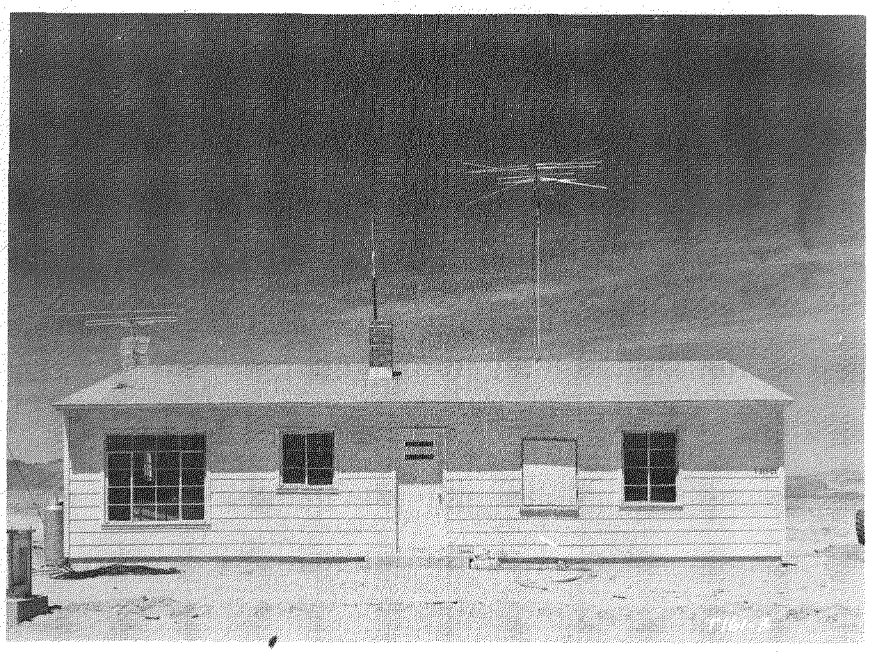


Fig. 2.7—One-story frame rambler house (31.1-c1) at 4700 ft, preshot. Note blast shutter in first-floor concrete shelter.

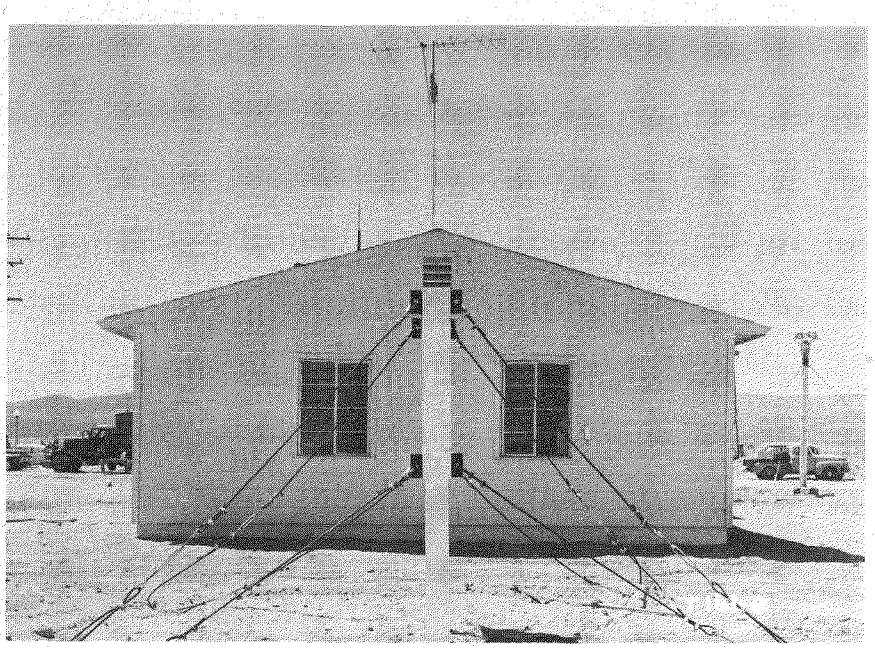


Fig. 2.8—One-story frame rambler house (31.1-c1) at 4700 ft, preshot.

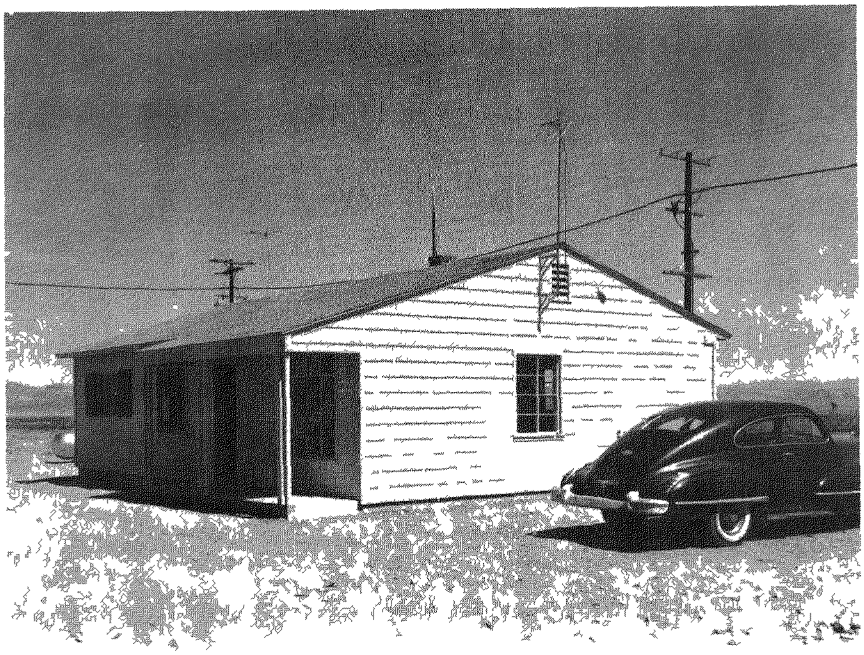


Fig. 2.9—One-story frame rambler house (31.1-c2) at 10,500 ft, preshot.

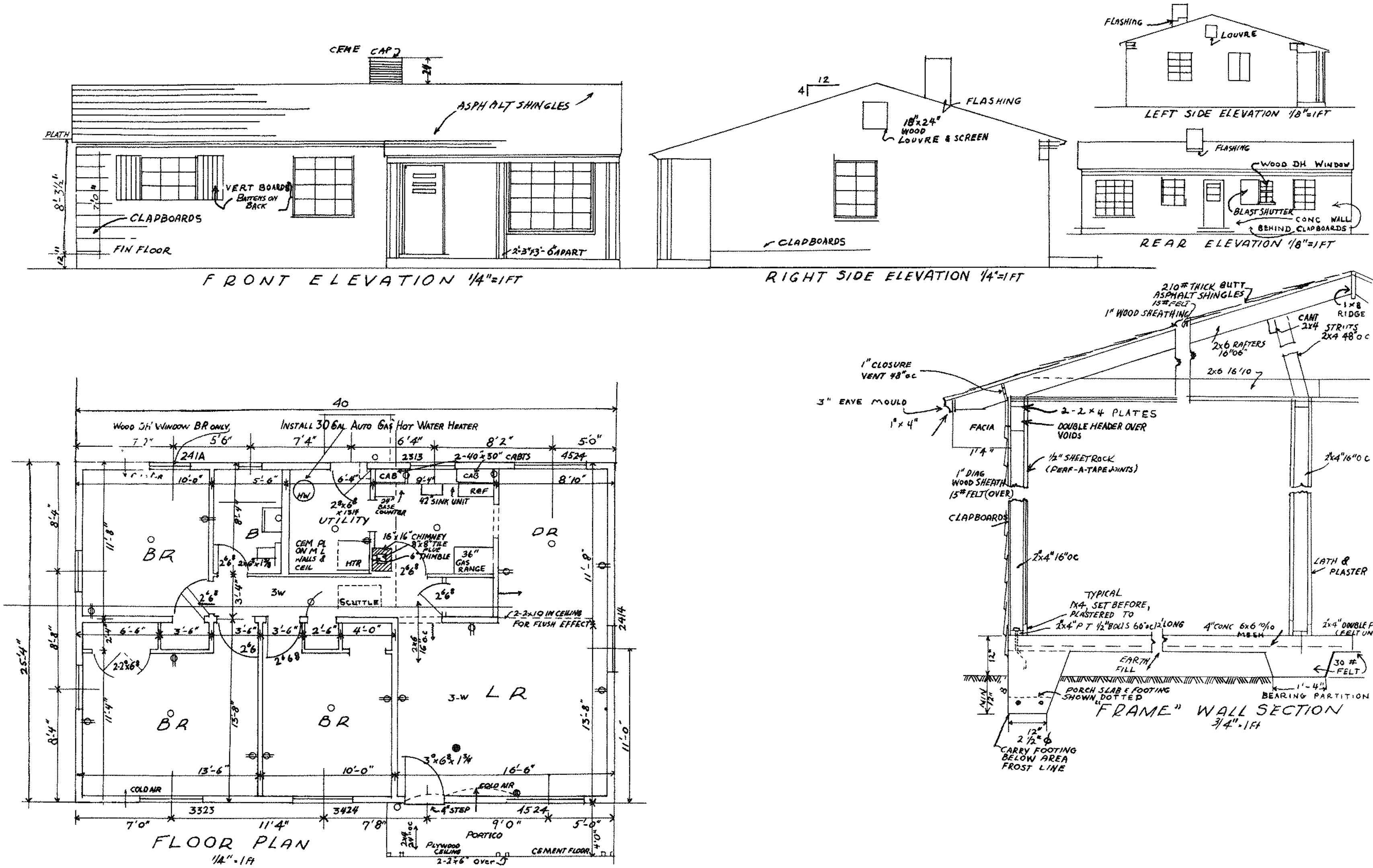


Fig. 2.10—One-story frame rambler house (31.1-c1 and 31.1-c2), plan and elevation.

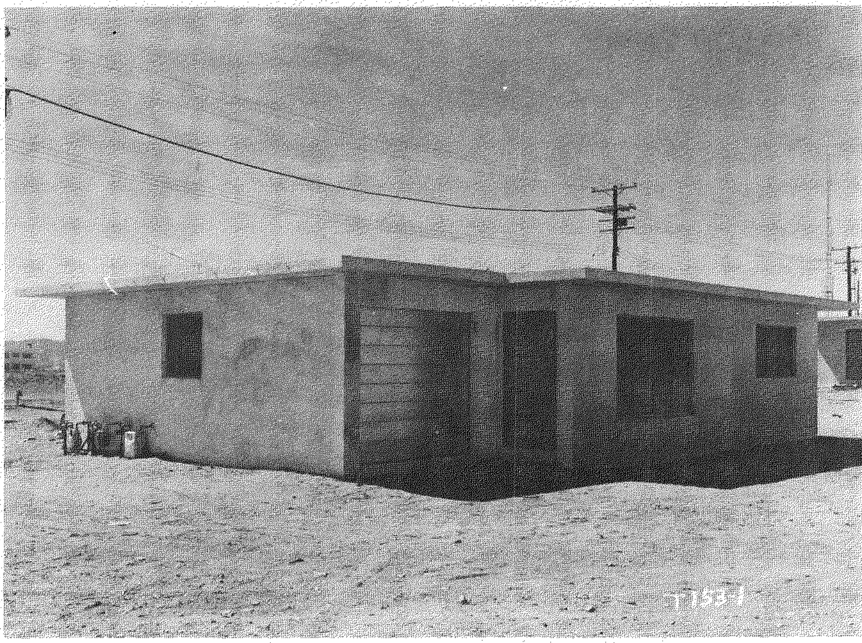


Fig. 2.11 — One-story precast lightweight concrete house (31.1-e1) at 4700 ft, preshot.

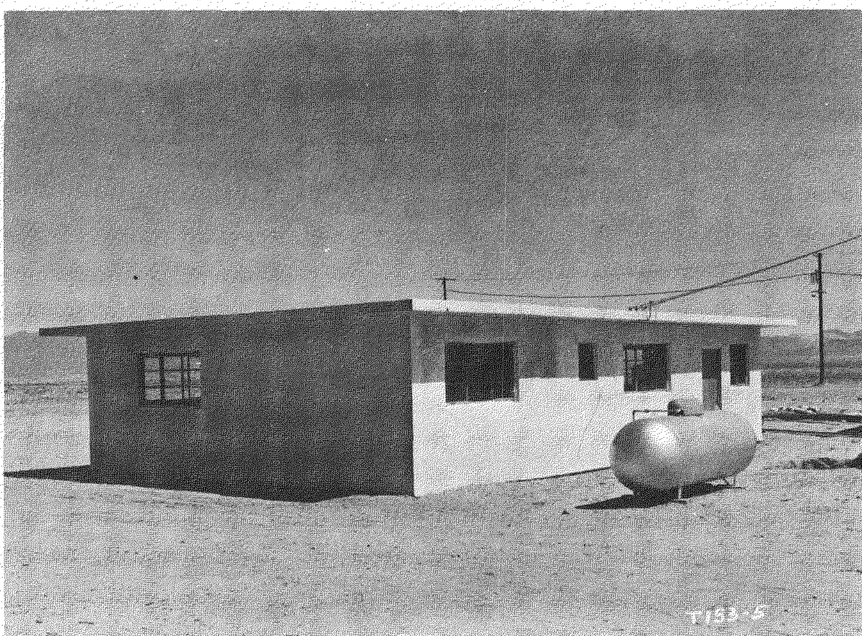


Fig. 2.12 — One-story precast lightweight concrete house (31.1-e1) at 4700 ft, preshot.

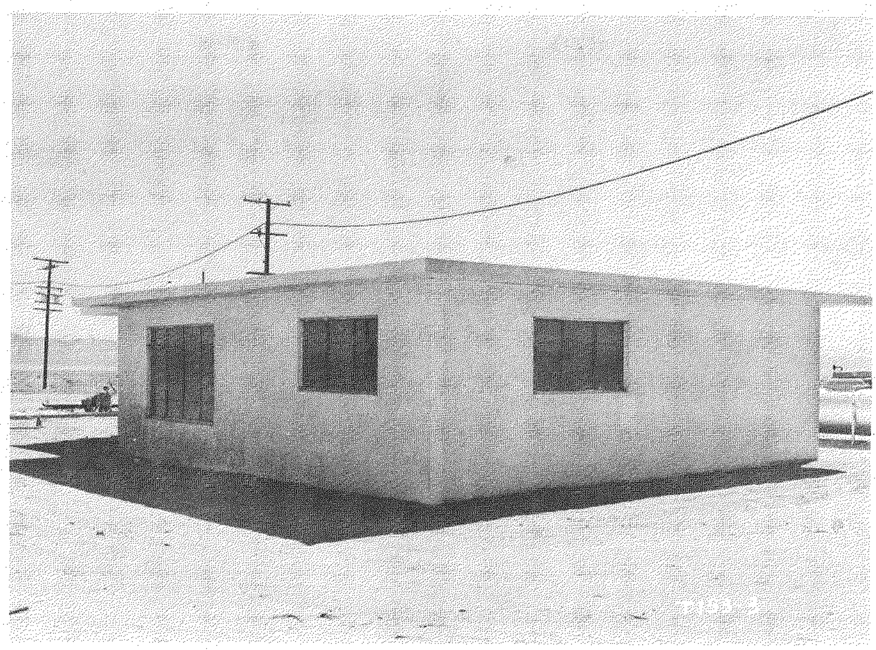


Fig. 2.13—One-story precast lightweight concrete house (31.1-e1) at 4700 ft, preshot.

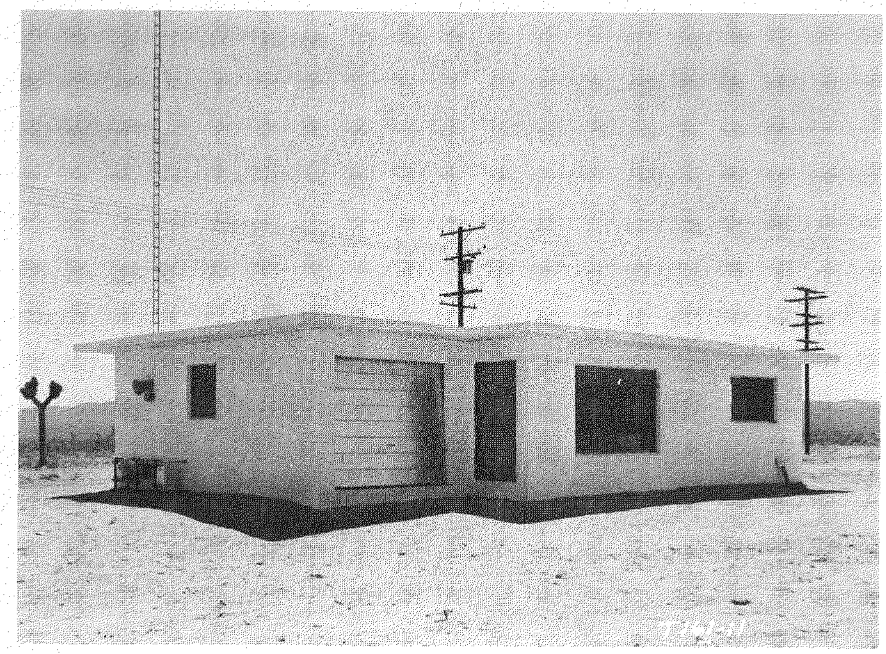


Fig. 2.14—One-story precast lightweight concrete house (31.1-e2) at 10,500 ft, preshot.

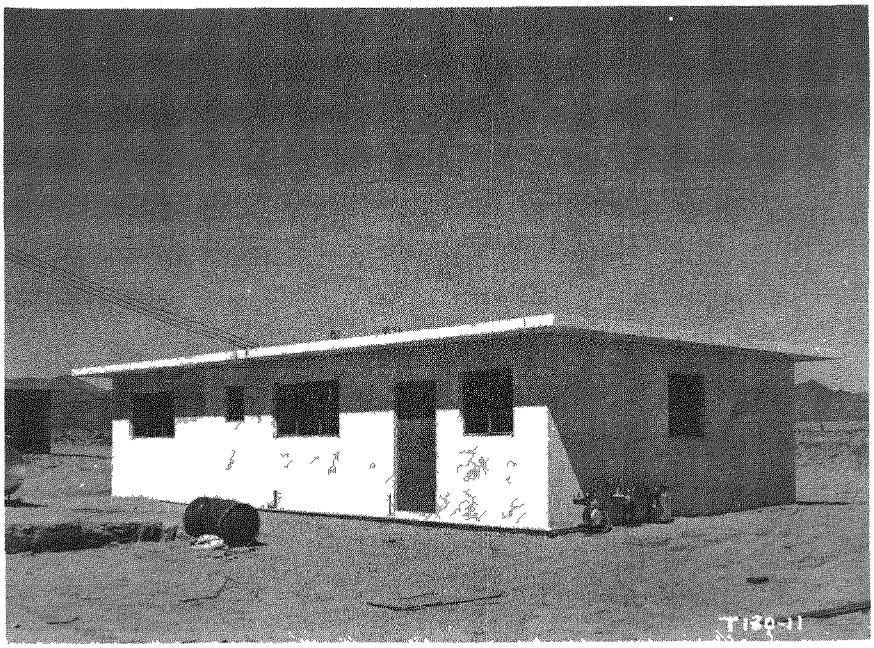


Fig. 2.15—One-story precast lightweight concrete house (31.1-e2) at 10,500 ft, preshot.

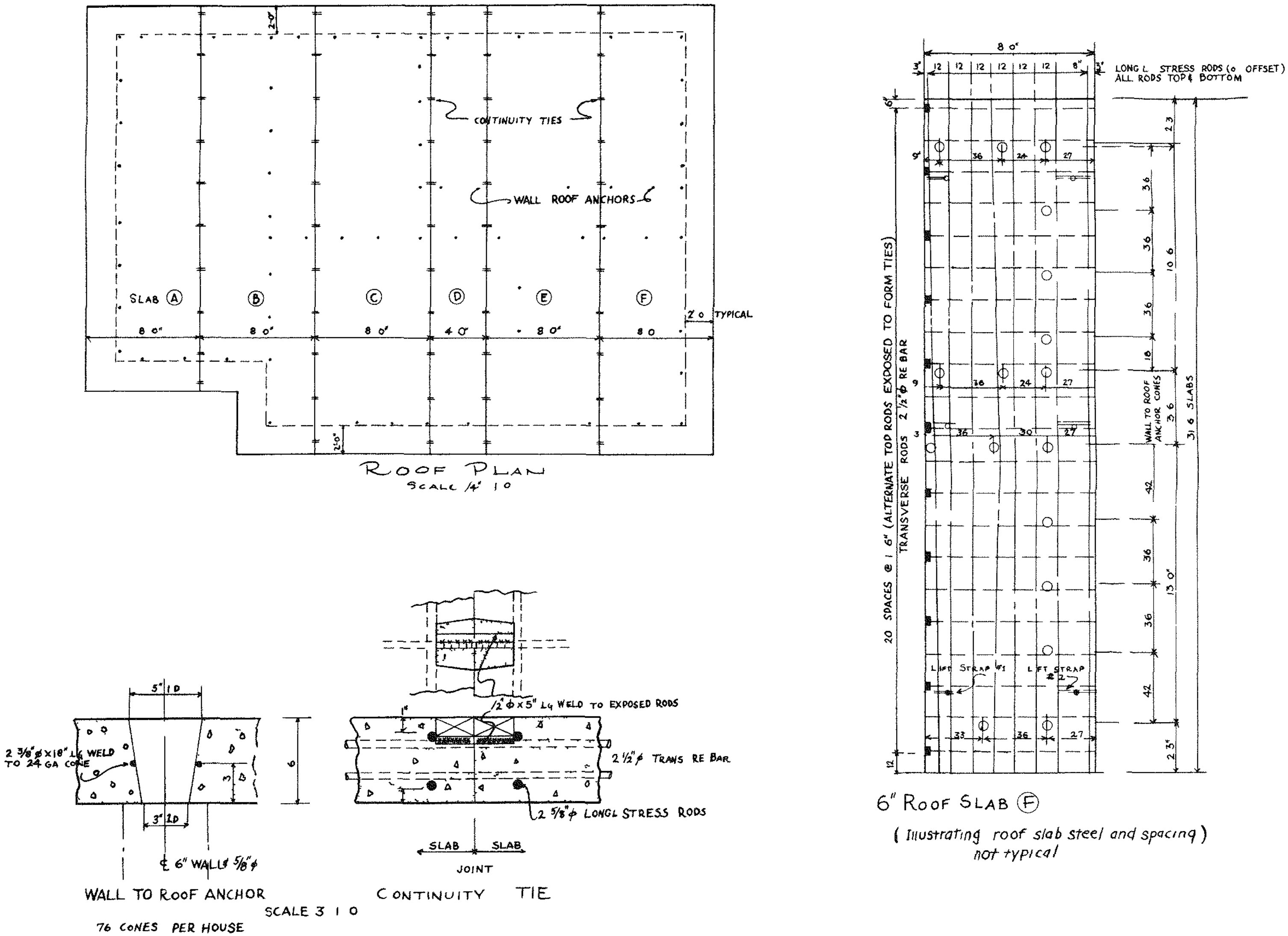
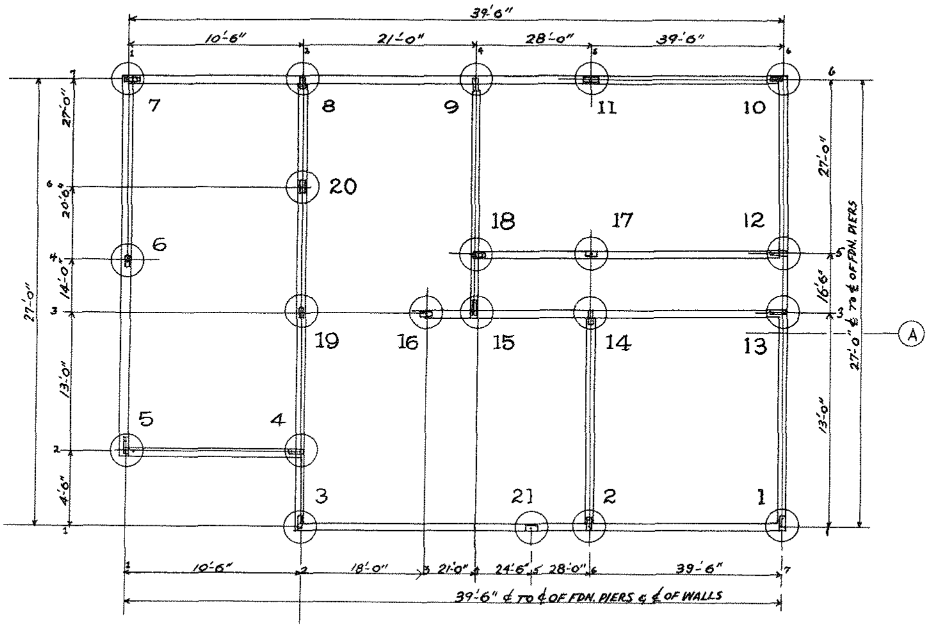
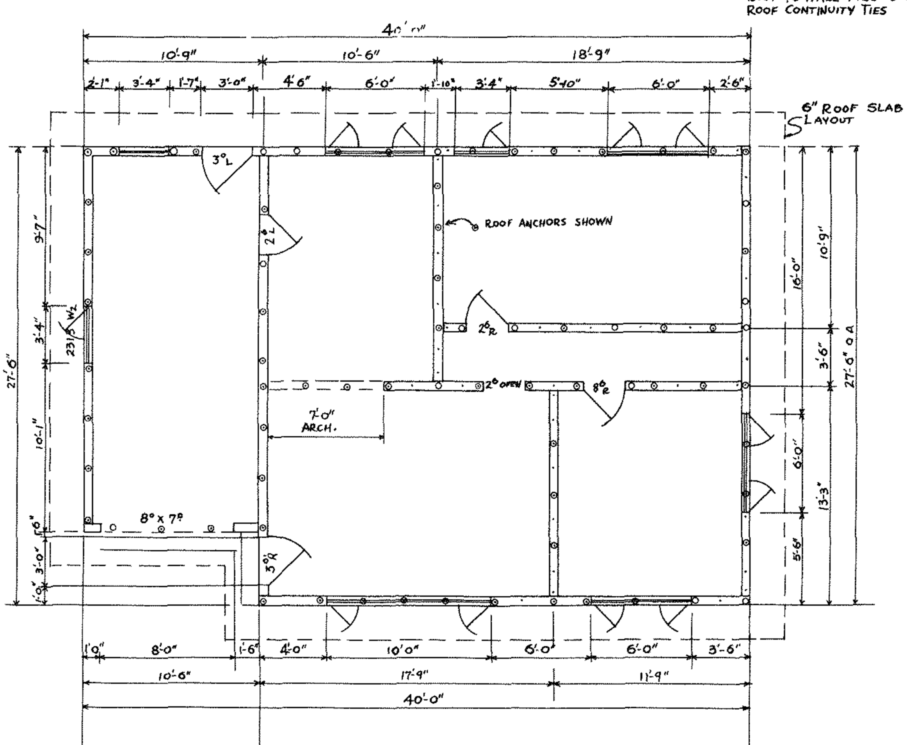


Fig. 2.16—One-story precast lightweight concrete house (31.1-e1 and 31.1-e2), roof plan and detail.



FDN. PIER LAYOUT

REINFORCING:
WALL PANELS - AS PER CODE
ROOF SLABS - " "
ROOF TO WALL TIES 3'0" o.c. MAX.
ROOF CONTINUITY TIES " "



FLOOR PLAN — SCALE-¼=1'-0"

(See facing page for legend.)

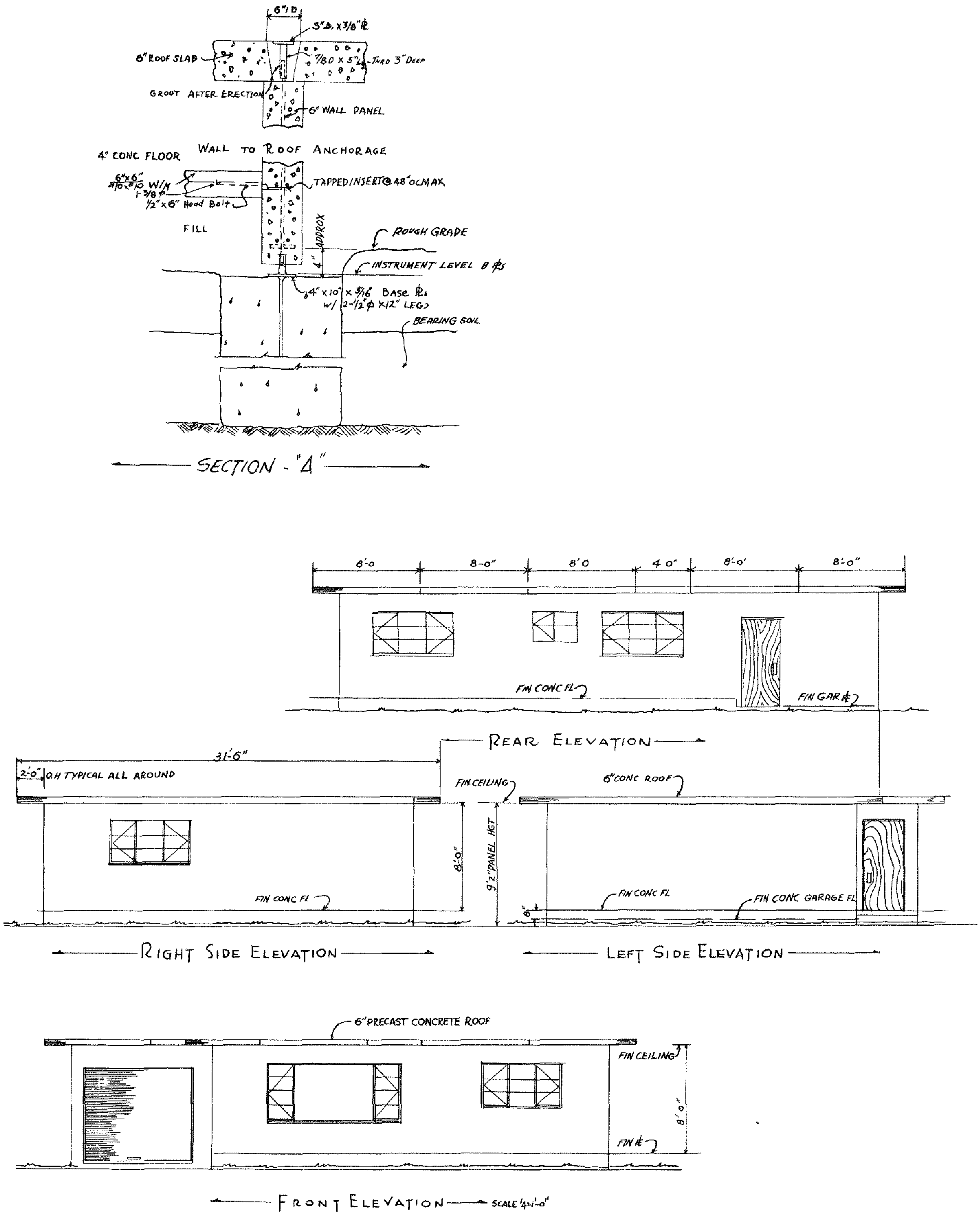


Fig. 2.17—One-story precast lightweight concrete house (31.1-e1 and 31.1-e2), plan and elevation.

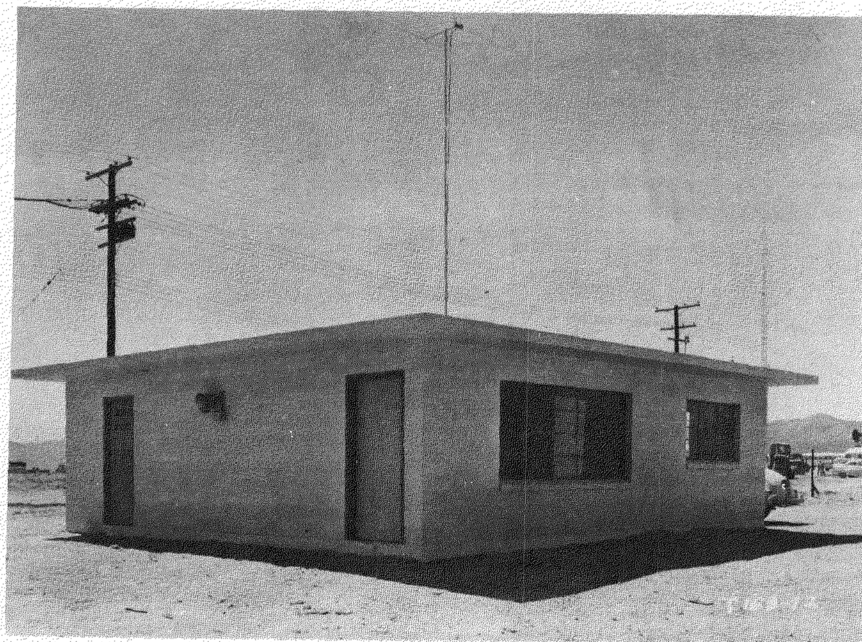


Fig. 2.18—One-story reinforced lightweight concrete-block house (31.1-f1) at 4700 ft, preshot.

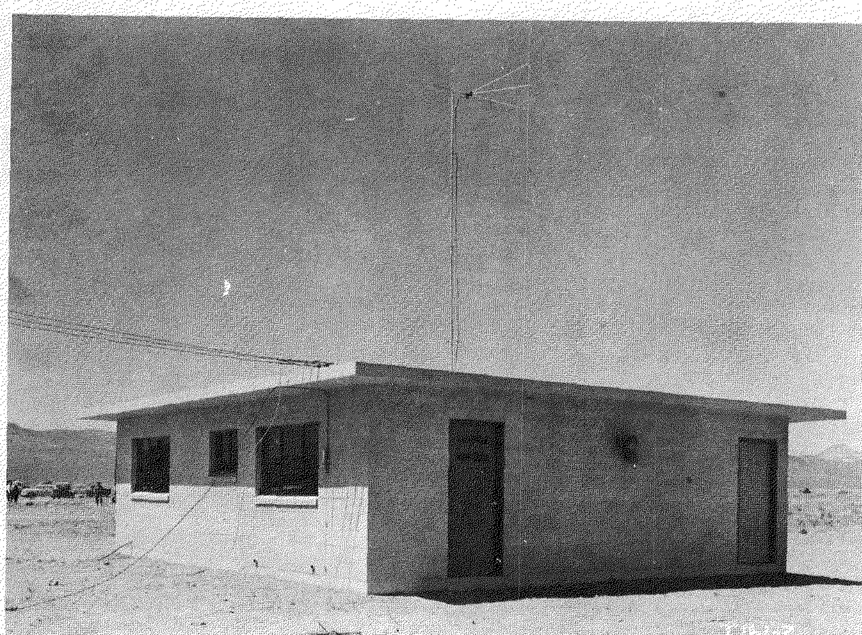


Fig. 2.19—One-story reinforced lightweight concrete-block house (31.1-f1) at 4700 ft, preshot.

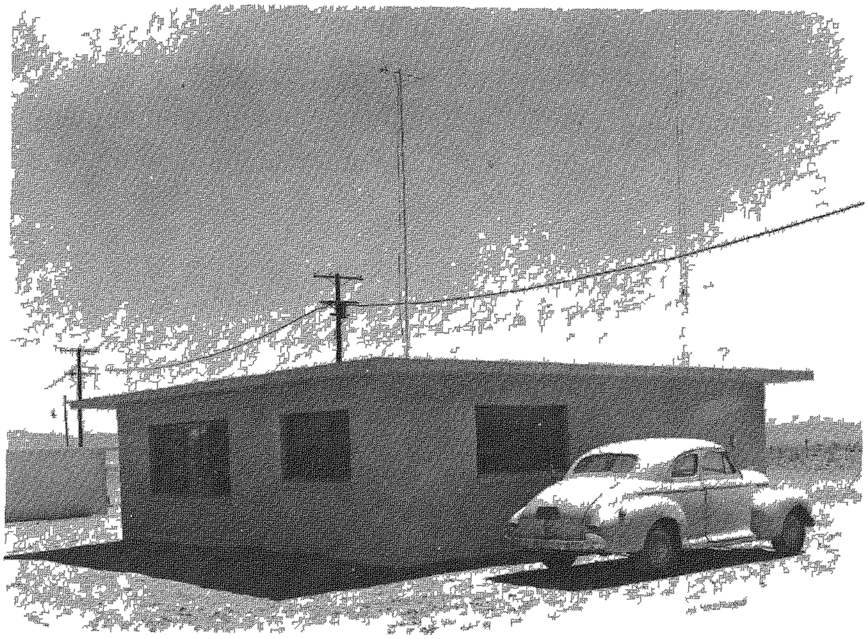


Fig. 2.20—One-story reinforced lightweight concrete-block house (31.1-f1) at 4700 ft, preshot.

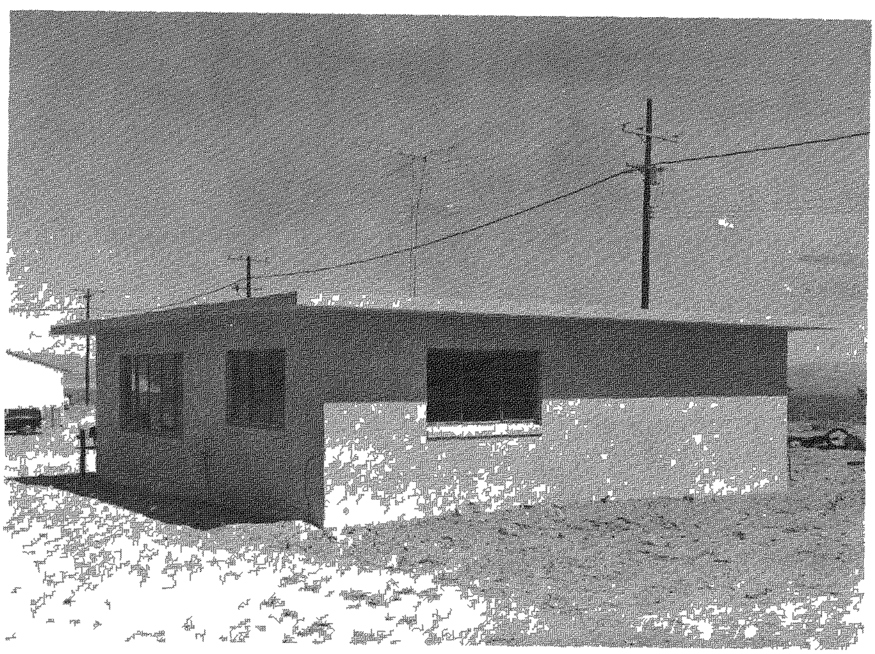
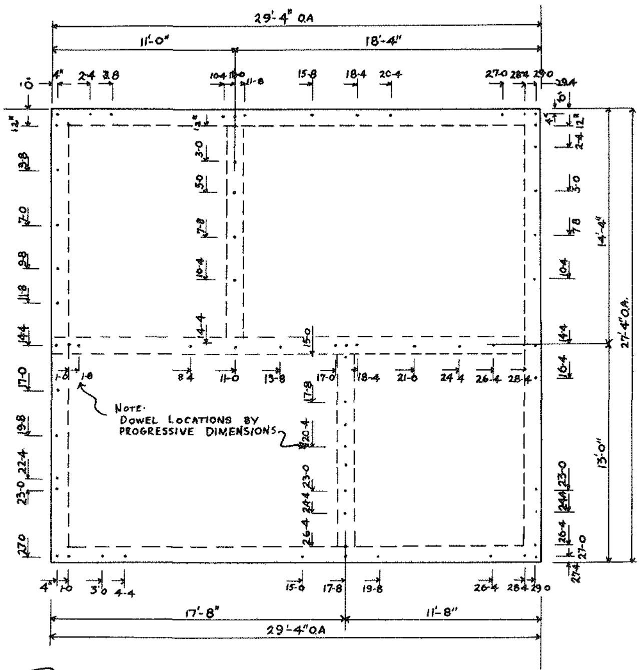
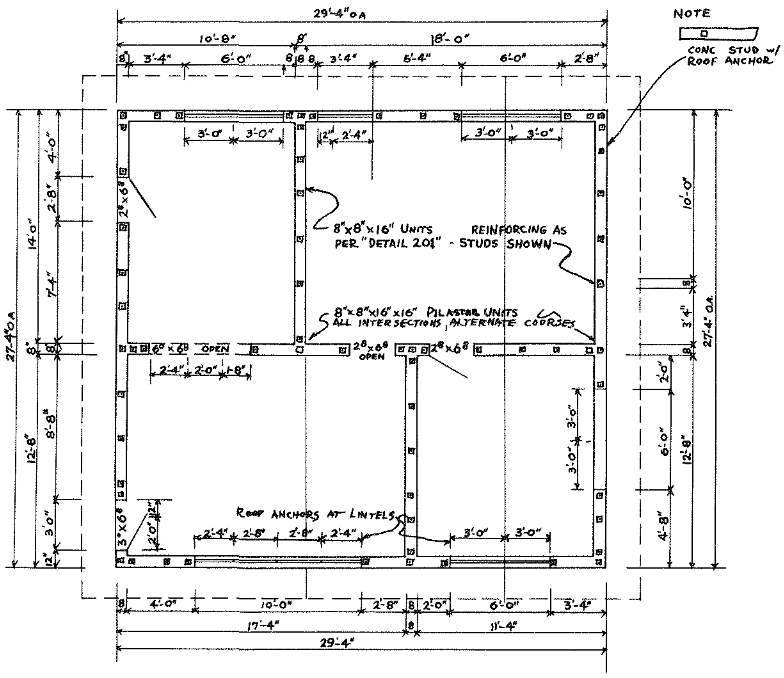


Fig. 2.21—One-story reinforced lightweight concrete-block house (31.1-f2) at 10,500 ft, preshot.



FOUNDATION PLAN



FLOOR PLAN
SCALE 1/4" 1'-0"

(See facing page for legend.)

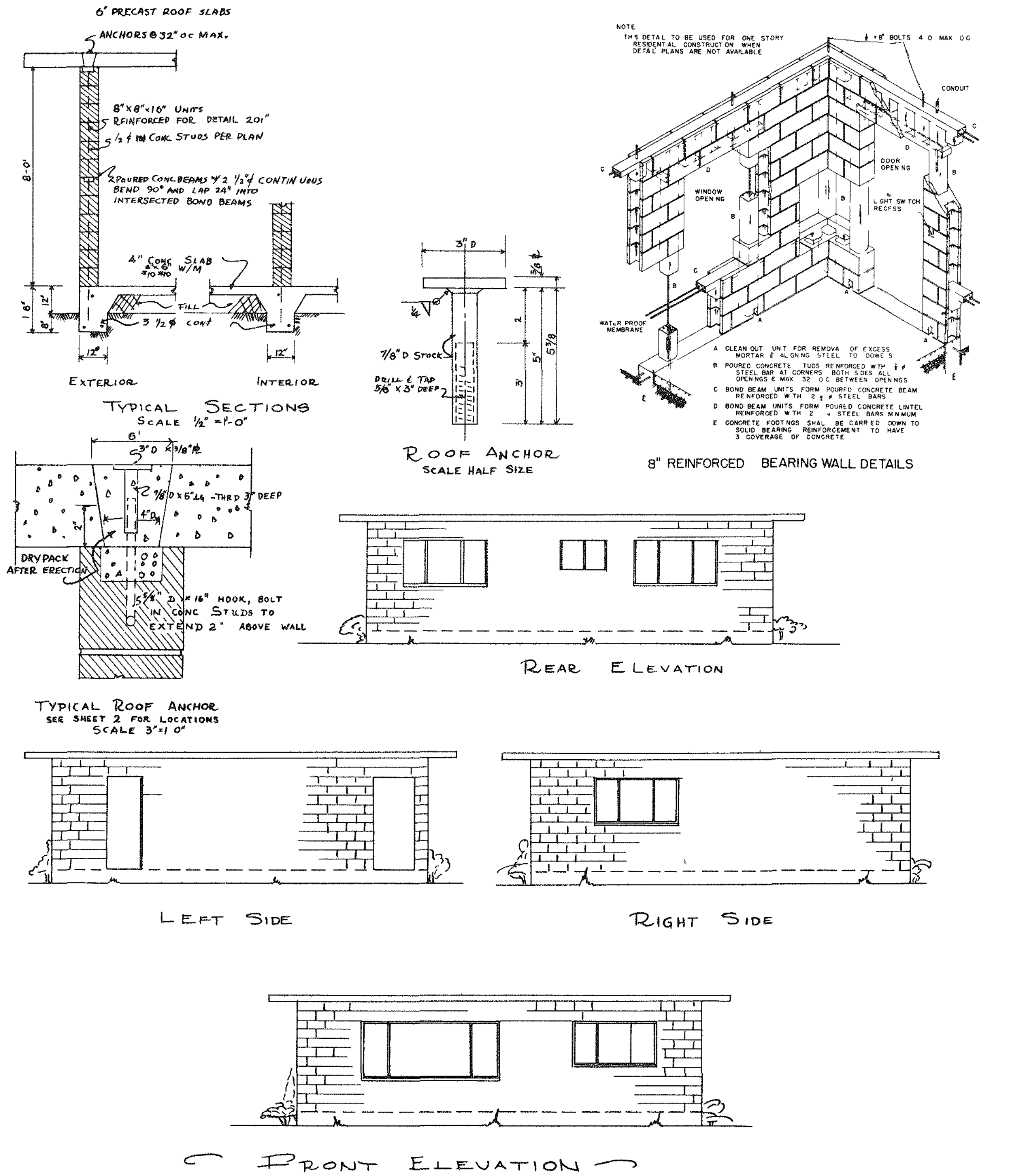


Fig. 2.22—One-story reinforced lightweight concrete-block house (31.1-f1 and 31.1-f2), plan, elevation, and detail.

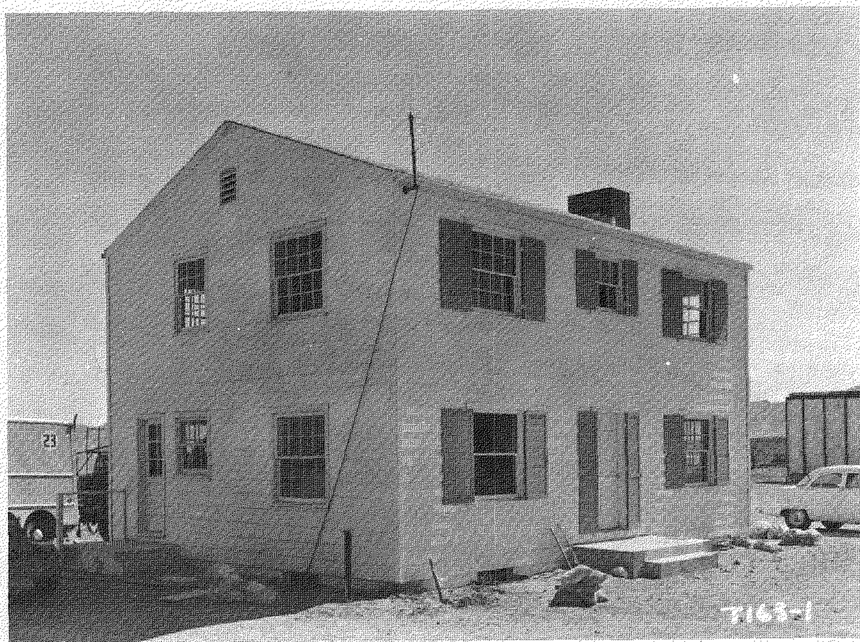


Fig. 2.23—Two-story frame (strengthened) house (31.1-b1) at 5500 ft, preshot.

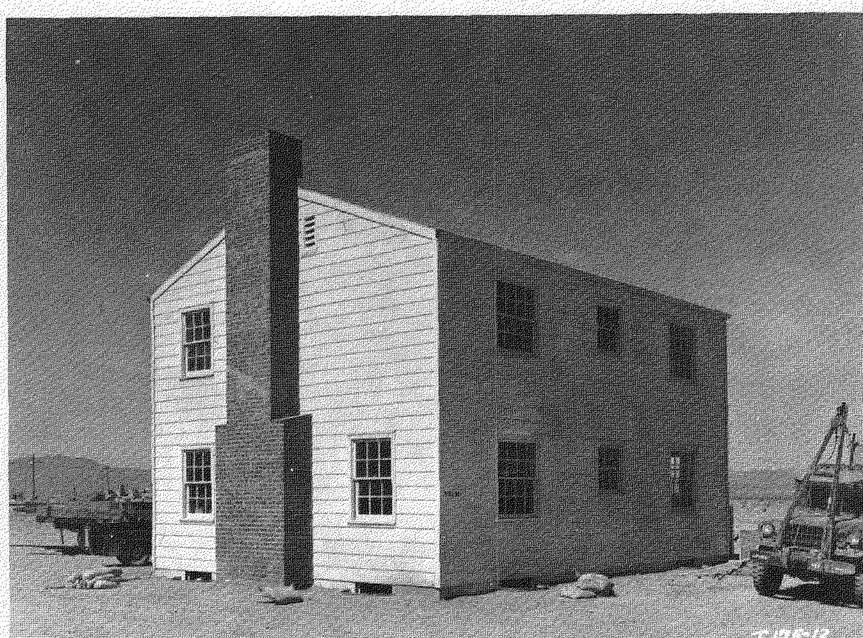


Fig. 2.24—Two-story frame (strengthened) house (31.1-b1) at 5500 ft, preshot.

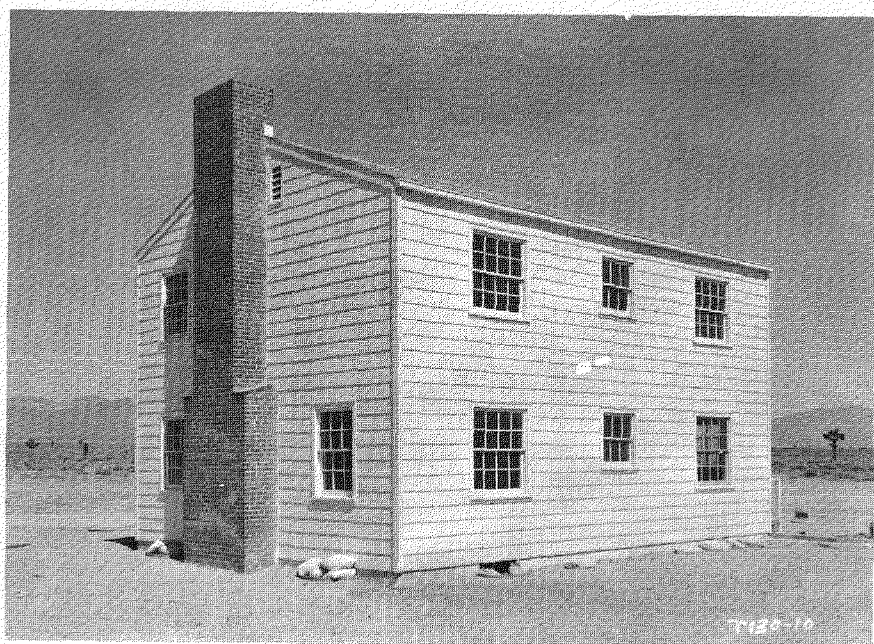


Fig. 2.25—Two-story frame (strengthened) house (31.1-b2) at 7800 ft, preshot.

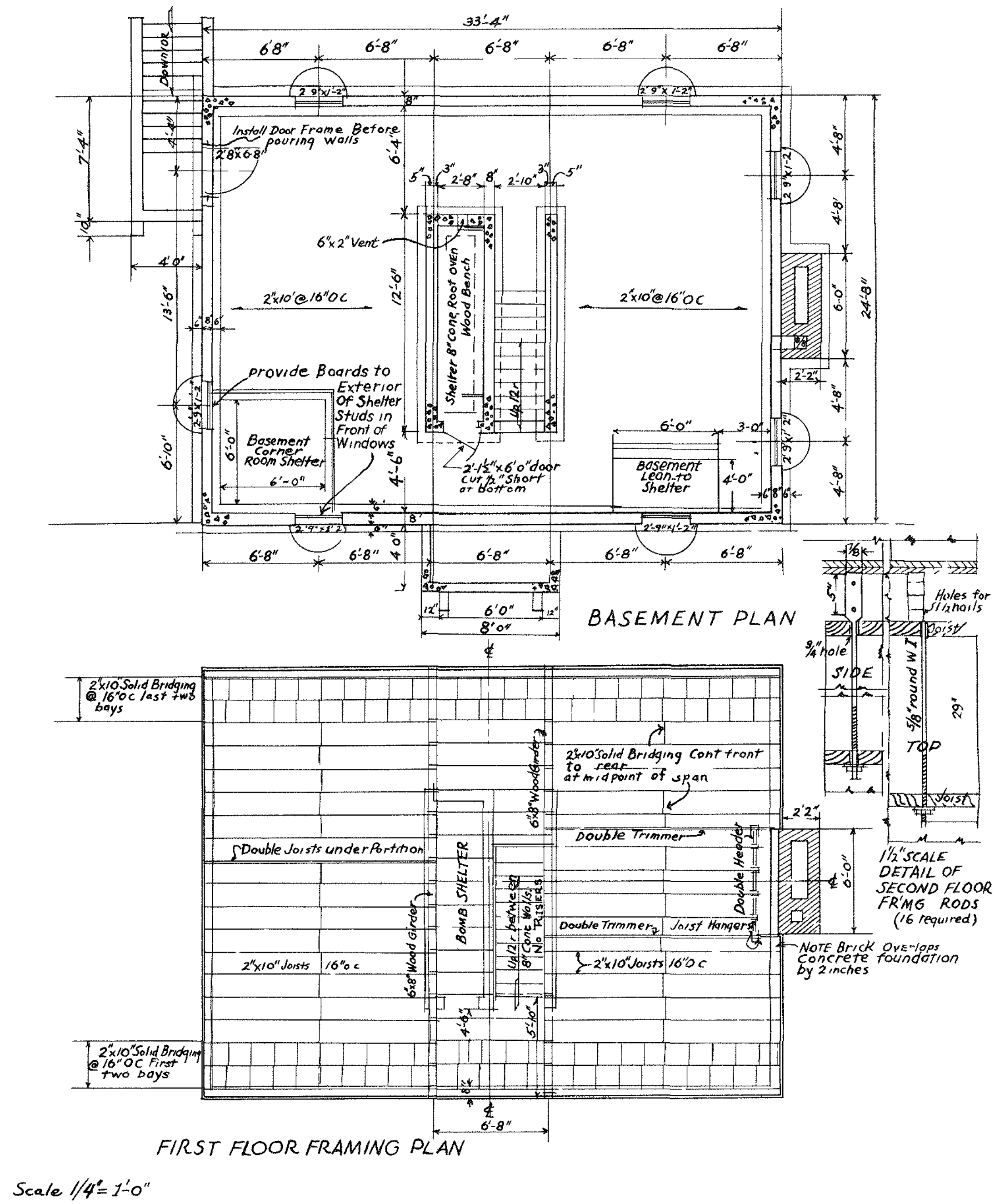


Fig. 2.26—Two-story wood-frame house (31.1-b1 and 31.1-b2), first-floor framing and basement plan.

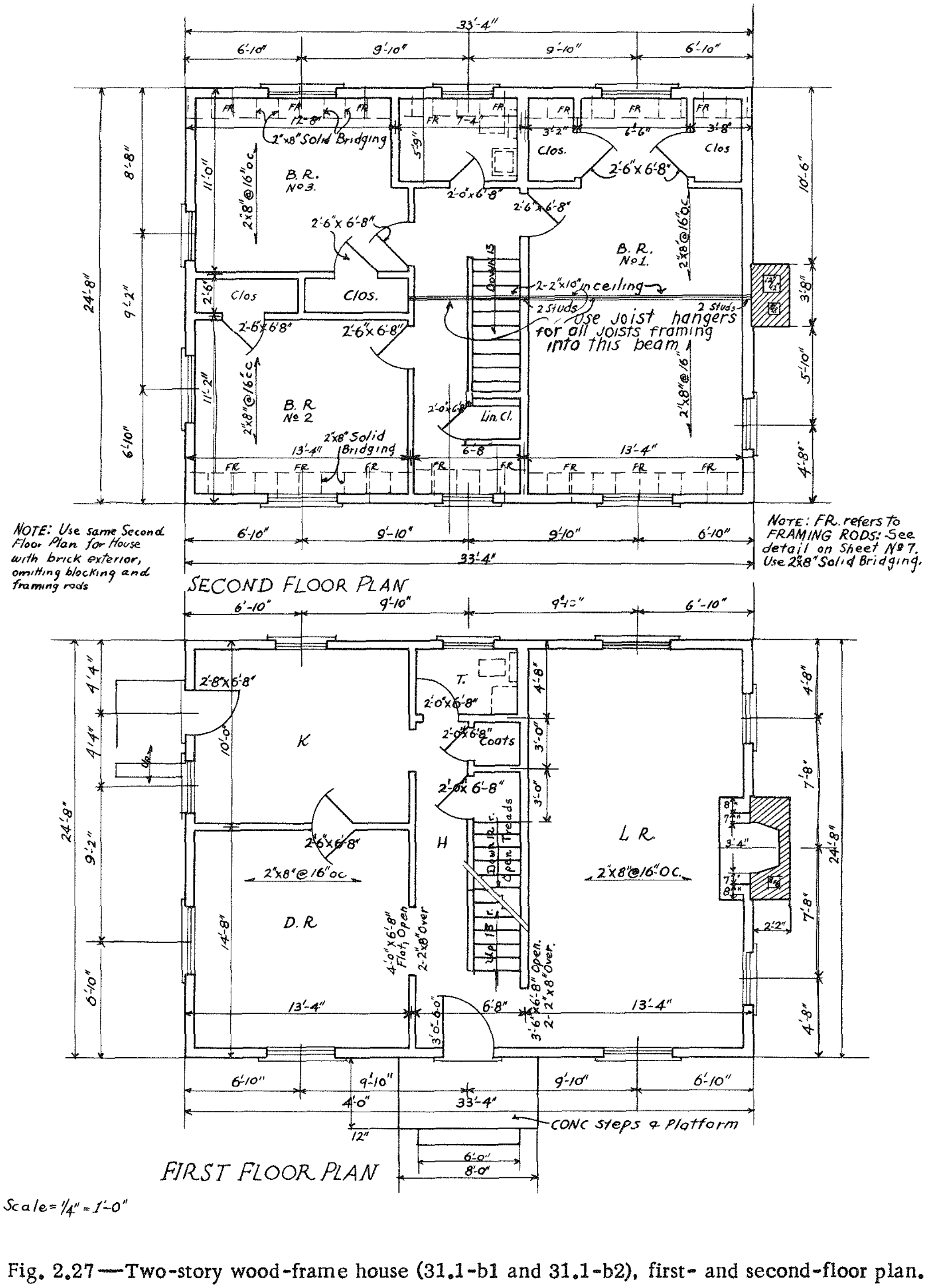


Fig. 2.27—Two-story wood-frame house (31.1-b1 and 31.1-b2), first- and second-floor plan.

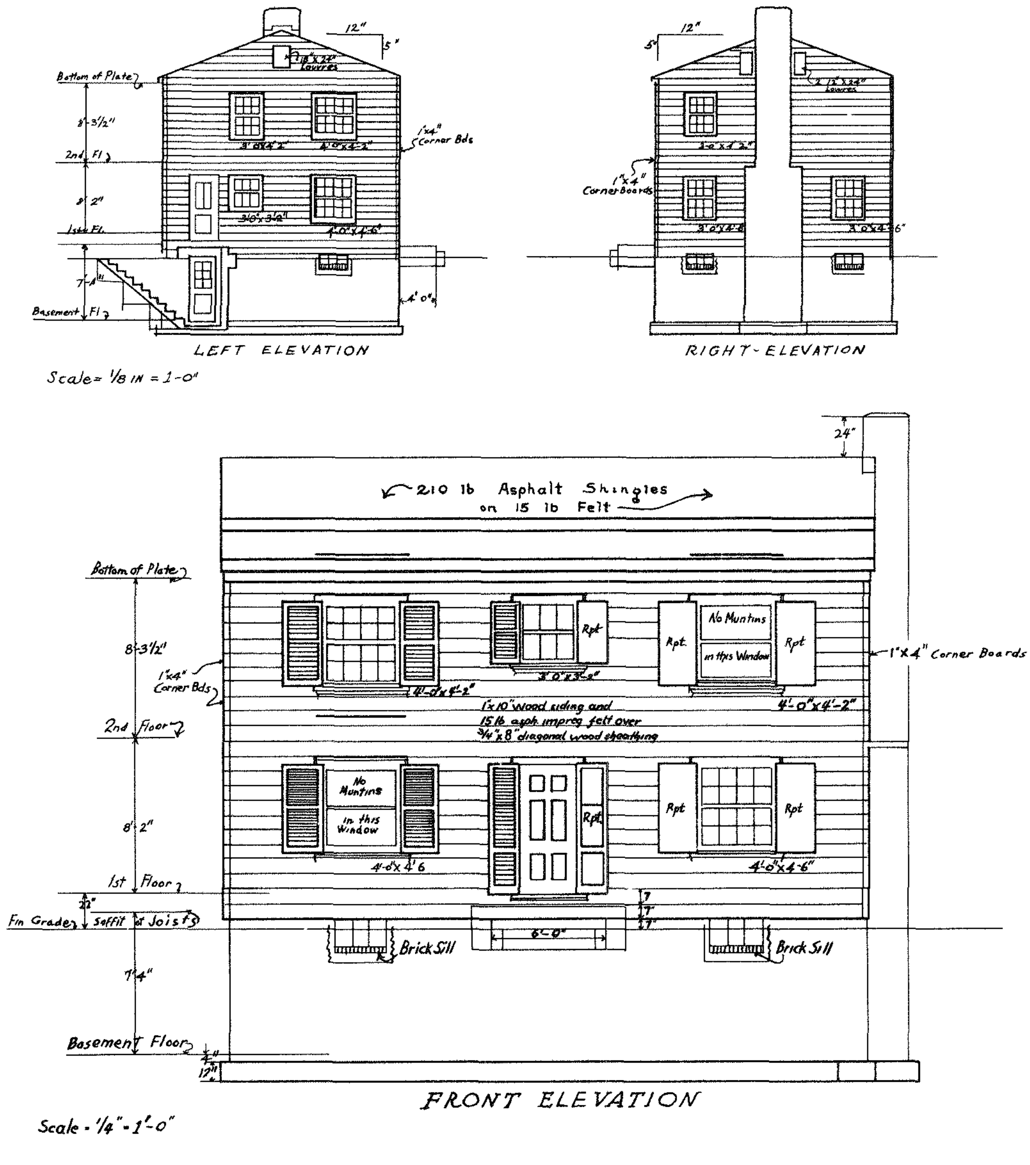


Fig. 2.28—Two-story wood-frame house (31.1-b1 and 31.1-b2), elevation.

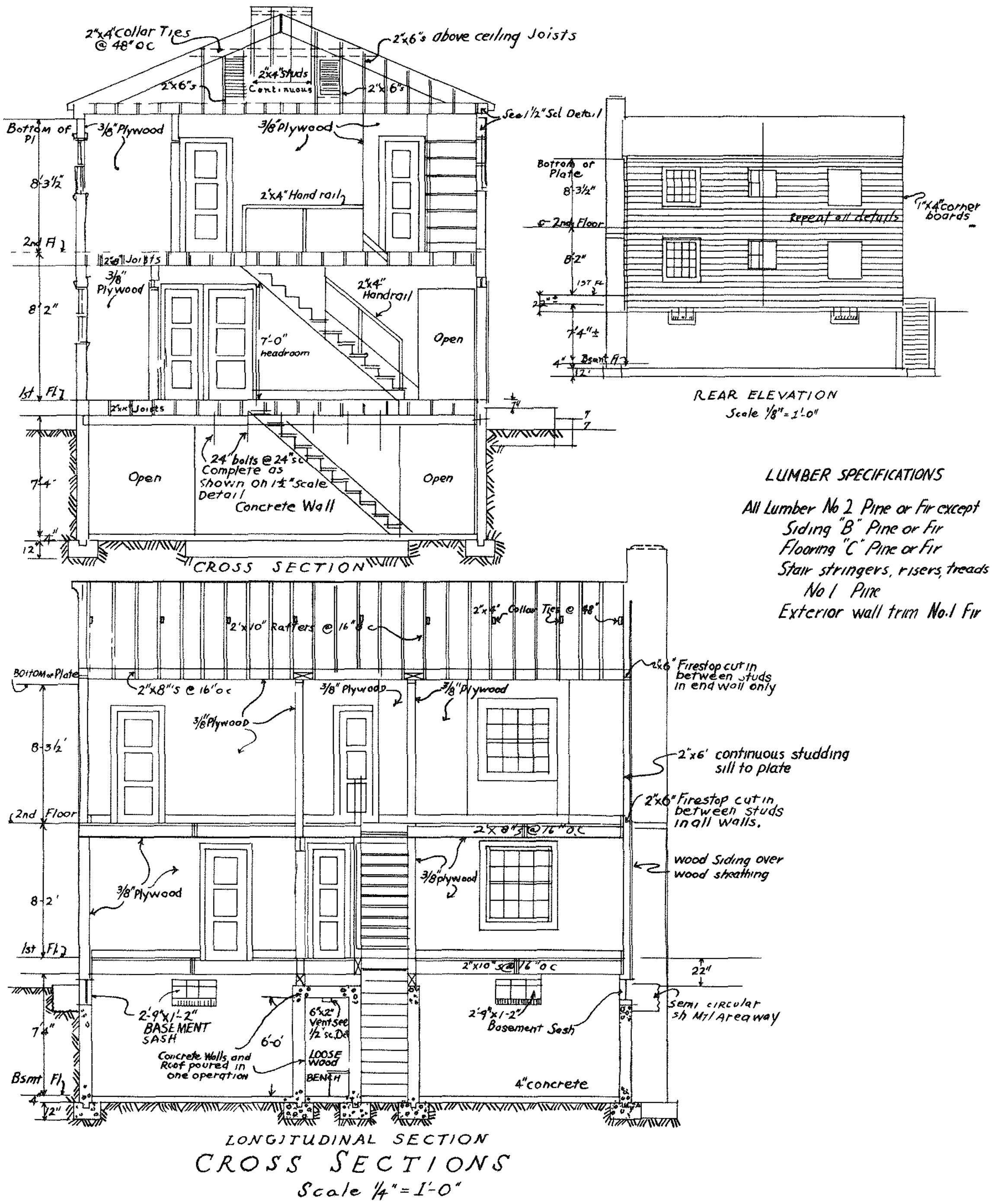


Fig. 2.29—Two-story wood-frame house (31.1-b1 and 31.1-b2), longitudinal section.

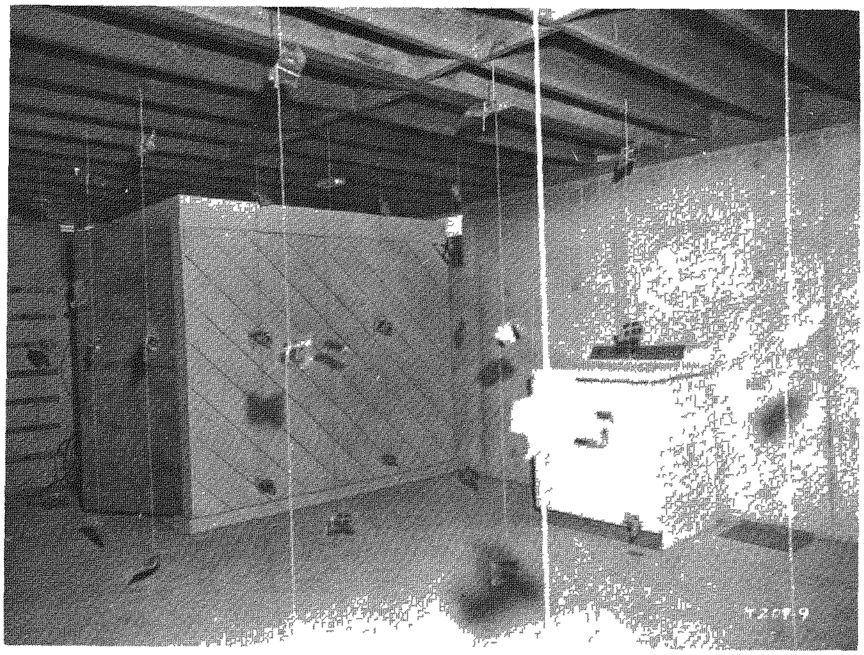


Fig. 2.30—Typical film-dosimeter installation in basement suspended in three horizontal layers from first-floor ioists.

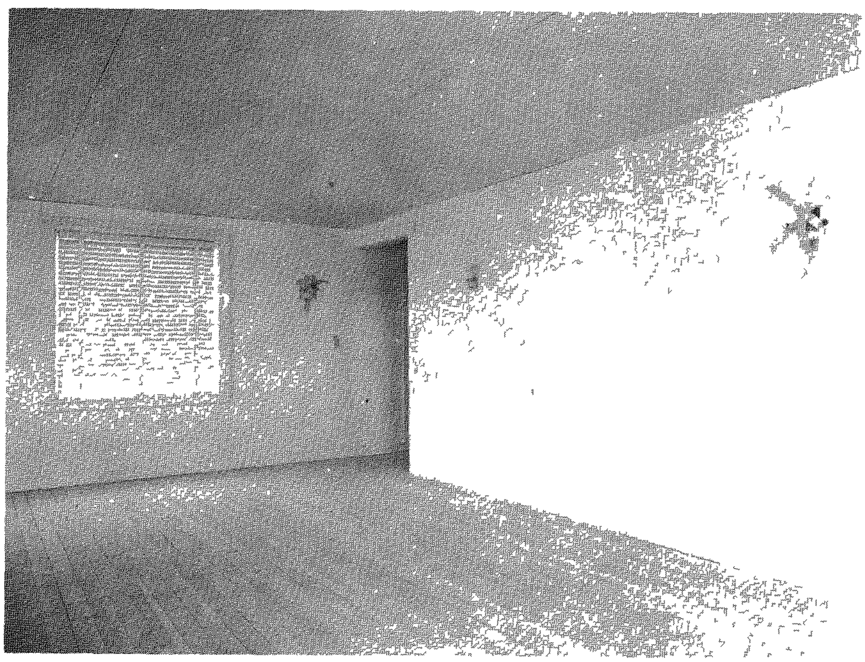


Fig. 2.31—Typical film dosimeter installation in rooms, showing attachment to walls in horizontal layer.

Chapter 3

TEST RESULTS

Aerial views of the test line postshot are shown in Figs. 3.1 and 3.2.

3.1 GAMMA RADIATION

On D day and during D + 1 day nearly complete recovery of the film dosimeters was accomplished. The collapse of two of the houses, with resulting debris, precluded recovery of a small number. The readings of the dosimeters and an analysis and discussion of the results will be furnished by Project 39.1 and reported in Report WT-1174.

3.2 THERMAL-RADIATION EFFECTS

The exterior woodwork of the houses was painted with light-colored paints to minimize the possibilities of ignition by thermal radiation from the nuclear explosion. All windows facing the blast were protected by either Venetian blinds or white opaque coatings on the glass to prevent thermal radiation from entering the house and causing fires by ignition of draperies, furniture, etc. A study of the motion pictures of the event revealed no burning or free-flaming; however, the exterior woodwork of the two-story brick and cinder-block house and of the one-story frame rambler house on the 4700-ft line showed evidence of charring to depths of not more than $^1/_{64}$ to $^1/_{32}$ in., and smoke was seen erupting from the wall face of the one-story concrete houses. Charring was also observed on the two-story frame house on the 5500-ft line. The two-story frame house located on the 7800-ft line showed scorch on the gray-painted shutters but not on the white paint used on the exterior siding. No charring or scorching was apparent on any of the houses located 10,500 ft from GZ. The effects from exposure to thermal radiation were over before the blast wave arrived.

3.3 BLAST EFFECTS

3.3.1 Two-story Brick House at 4700 Ft (31.1-a1)

The measured overpressure at this location was 5.1 psi (735 psf).

The aboveground portion of the house was demolished beyond repair (Fig. 3.3). The exterior brick and cinder-block walls had exploded outward into the yard around the house, very little masonry debris falling on the floor framing. The chimney fell to the side of the house and lay on the ground broken into large sections. The roof was demolished and blown off, the rear side of the roof being lifted off and deposited on the ground on the far side of the house about 50 ft to the rear. Some of the bearing partitions, those around the staircase and first-floor hall and those on the second floor, remained standing but were badly racked. The stair from first to second floor remained standing. The second floor partially collapsed on the first floor, but on one side of the house about 50 per cent of the ceiling joists remained hanging from the partition, many of the joists did not split, and part of the second-floor construction remained where supported by bearing partitions. Many of the second-floor joists were not broken or split and acted as cantilevers from the bearing partitions (Fig. 3.4).

The first floor partially collapsed into the basement as a result of the fracturing of practically all the long-span first-floor joists at the center of the spans. This was probably caused by the overpressure loading and the load of the second floor, which fell upon it. The floor joists were hanging so as to provide little support for the floor except the area between post and beam supports, the debris being supported by the diaphragm action of the sub and finish flooring. The floor on each side of the post and beam support was subject to imminent collapse. One wood beam under a bearing partition was badly split. The other wood beam and all four pipe columns appeared in good condition and showed no evidence of movement. The basement stairs remained standing and in good condition. The 12-in. concrete-block basement walls below ground surface suffered very minor damage, indicating a ground shock wave relatively minor compared to the air shock wave.

The second-floor system offered considerable resistance to the external lateral pressure of the blast; it appears that the blast wave, as it enveloped the house, blew in the windows and doors and built up a high overpressure inside the house, at the same time weakening the front wall and probably the others. As the pressure outside dropped off in intensity, the high-pressure volume of air inside the house expanded and forced the walls outward, collapsing the structure. The second-floor system as designed offered very little resistance to internal lateral pressure since the fire-cut joists were designed to bear on, but were not secured to, the cinder-block wythe of the exterior wall.

3.3.2. One-story Frame Rambler House at 4700 Ft (31.1-c1)

The measured overpressure at this location was approximately 5.1 psi (735 psf).

The house was demolished beyond repair; only the reinforced-concrete bathroom shelter remained intact (Figs. 3.5 to 3.8). The roof was blown off, one section of the roof was found lying 100 ft to the rear of the house, the rafters split and broken. The sidewalls at the gable ends were blown outward and fell to the ground about 75 ft to the rear of the house. A portion of the front wall was still standing but was leaning inward. The front and side walls on the living room side of the structure were lifted completely from the slab foundation, the wall plates being pulled from the anchor bolts, and demolished. The reinforced-concrete bathroom shelter, by virtue its firm resistance to any effects of the blast, served to give some measure of additional support to the remnant of the structure. Had it not been for the shelter, it is quite possible the structure might have been blown entirely from its slab foundation.

3.3.3 One-story Precast Concrete House at 4700 Ft (31.1-e1)

The measured overpressure at this location was approximately 5.1 psi (735 psf).

The building withstood the blast with only very minor structural damage. Replacement of demolished or badly damaged doors and windows would make this house available for occupancy. (See Figs. 3.9 to 3.16.)

There was some indication that the roof slabs at the front were lifted slightly from their bearings but not sufficiently to break any connections. The rubber gasket between the roof slabs and walls was blown loose and showing. The walls were cracked slightly over the kitchen window and at the rear corner of the garage. The side wall of the garage was cracked as a result of a bowing outward at the center of the span, leaving an inch space between the floor slab and wall. This could have been caused by failure of one or more of the threaded hook bolts. In the rear bedroom, joints showed some evidence of minor movement at lug connections. In certain areas the concrete around the slab connectors spalled, showing the connectors. The steel sashes in the windows generally remained in place but were too distorted for reuse. Glass in the front and side windows as well as some in the rear windows was blown out. The aluminum garage door was blown into fragments. Exterior doors to the house were demolished. No doors were installed in the partitions.

3.3.4 One-story Concrete-block House at 4700 Ft (31.1-f1)

The measured overpressure at this location was approximately 5.1 psi (735 psf).

The building withstood the blast with only minor structural damage. Replacement of doors and windows would make this house available for occupancy. (See Figs. 3.17 to 3.20.)

There was minor evidence that the roof slabs had been moved from their bearing but not sufficiently to break any connections. The concrete wall under the front living-room window was pushed in about 4 in. on the concrete slab. Investigation revealed that the design did not provide for dowels between the wall and floor slab under window openings. Some cracks developed in the wall above the same window, probably owing to improper installation of the reinforced lintel course and the substitution of a pipe column in the center span of the window. Exterior doors were blown inward and completely demolished. Glass in the front windows was blown in; the steel frames were distorted but remained in place. The rear windows, glass and frames, were blown out.

3.3.5 Two-story Frame House at 5500 Ft (31.1-b1)

The measured overpressure at this location was approximately 4 psi (576 psf).

The superstructure of the house suffered severe damage; the house would not be suitable for occupancy without extensive and economically inadvisable major repairs. (See Figs. 3.21 to 3.31.) Certain of the redesigned features appeared to perform their function well, particularly the reinforced-concrete foundation wall, the shear walls supporting the main girders in lieu of pipe columns, the improved connections between the frame walls and concrete foundation walls, and, except on the front of the house, the improved window-frame anchorage. The strengthened superstructure, however, was still inadequate to resist the overpressure of approximately 4 psi to which it was subjected.

Notwithstanding the increase in size of the roof rafters from 2 by 6 in. to 2 by 10 in., the blast broke the rafters of the front half of the roof at the midspan and flattened the entire front section, with the sheathing and roofing attached, against the ceiling joists. Most of the 2 by 10 in. rafters were split lengthwise. The rear half of the roof was lifted from the house and was dropped to the ground 25 ft to the rear; the sheathing and most of the shingles were still attached.

Very few of the ceiling joists were broken. Large sections of plywood ceiling were blown down into the rooms below. Evidence of severe racking was visible throughout the remains of the house. The plywood covering the living-room bearing partition was racked $\frac{1}{2}$ in. out of level at the ceiling in a 4-ft width of sheet. Noticeable dishing in of the front wall was observed. Some of the 2 by 6 in. studs around the openings in the front wall were broken. Partically all doors and windows were demolished, the front windows being blown in with such force that pieces of the sash or frame were driven through the plywood surfacing on the interior walls. The upper portion of the chimney was toppled outward at right angles to the end of the house. Above the hearth line the chimney was shoved $2\frac{1}{2}$ in. toward the rear of the house and rotated slightly. The exterior wall to the rear of the chimney was bulged out of line several inches and pulled away from the second floor and ceiling framing. The front gutter was found lying on the ground 60 ft in front of the house, and the rear gutter, in two sections, was blown 150 to 200 ft to the rear of the house. The first-floor joists were split or broken; the floor was near collapse and was held up principally by the sub and finish flooring. The fireplace hearth split off and dropped. The second floor and the ceiling of the first floor showed little damage, indicating pressure equalization above and below the floor. There was no apparent damage to the concrete shear walls supporting the main girders nor to the concrete basement foundation walls, indicating that earth shock was not severe. The basement stairs appeared undamaged.

3.3.6 Two-story Frame House at 7800 Ft (31.1-b2)

The measured overpressure at this location was approximately 2.6 psi (375 psf).

This house, a counterpart of the house described under Sec. 3.3.5, suffered relatively heavy damage, but its condition was such that it could have been made available for emergency housing by shoring and not too extensive repairs, such as new roof framing and patched roofing, shoring of fractured joists, replacement of loosened plywood interior panels, and the installation of new windows and doors.

Because of its greater distance from GZ (hence lower overpressure), this dwelling suffered less damage than the dwelling located at 5500 ft (Figs. 3.32 to 3.41). Although the roof was not blown off, it was severely damaged. A number of the roof rafters on both sides of the ridge member were split and the 1 by 12 in. ridge member was badly split. The roof sheathing and most of the asphalt-strip shingles remained intact, although, when the front gutter was blown off (its broken sections being deposited 100 to 150 ft to the rear of the house), it peeled off shingles a foot or two back from the eave and shingles were peeled off a foot or more at the near side of the ridge of the roof. The gutter and shingles on the rear half of the roof remained intact. The ceiling joist suffered only minor damage, but the ceiling framing was lifted about 6 in. from its attachment to the bearing partition dividing the front and rear bedrooms. The center girder over the master bedroom ceiling was lifted 2 in. out of its supporting stirrups and was pulled away from the ceiling joists. The nails fastening the strap-iron joist ties over the center girder were sheared off on the blast side of the house at some joists.

Most of the plywood ceiling in the rear bedroom on the second floor was blown down into the room. In the front bedroom, the master bedroom, and in the hall the plywood ceiling covering and ceiling joists were blown upward about an inch or more. Some of the plywood ceiling boards were blown free of their fastenings. Several of the interior doors were blown from their hinges. The exterior walls and the interior partitions did not appear to have suffered major structural damage, although there was evidence of considerable racking, which caused loosening of the connections at the ends of the ceiling joists. A number of the first-floor joists were cracked and fractured, but no debris was deposited in the basement because the subflooring and flooring remained intact. The brick chimney was damaged but remained in place. The upper part of the chimney was sheared loose and was rotated counterclockwise about 4 in. as was a lower portion about 18 in. above the ground.

Shutters on the front of the house were loosened and received some damage but withstood the blast. The wooden window sashes on the front and sides were blown in and smashed; the rear windows were damaged, and the front door was blasted in and damaged the stair rail. The exterior basement door was blown into the basement. The stairs to the basement and to the second floor appeared to have no structural damage. The Venetian window blinds ended up as piles of rubbish. Only slight damage was suffered by the walls and ceilings of the first-floor and second-floor construction. The concrete basement walls, the concrete shelter, and the concrete shear walls in the basement showed no damage.

3.3.7 Two-story Brick House at 10,500 Ft (31.1-a2)

The measured overpressure at this location was approximately 1.7 psi (245 psf).

This house was a counterpart of the house described under Sec. 3.3.1. Although this house suffered relatively heavy damage, its condition was such that it could be made available for emergency occupancy by shoring and other not too extensive repairs (Figs. 3.42 to 3.44).

There was no apparent damage to the masonry of this house. The structure suffered considerable damage to the roof and second-floor ceiling framing. The connections of the rear rafters to the ridge failed, and the rafters dropped 4 to 6 in. below the ridge. The ridge split in the center portion, and some of the 2 by 4 in. collar beams broke in half. The ceiling joists over the rear bedroom split at midspan, and the lath and plaster ceiling was blown down into the room. The second-floor framing suffered little or no damage. A few first-floor joists were fractured. The glass in the front and side windows was blown in, and the glass in the rear windows suffered some damage. The exterior doors were blown in and demolished, and several interior bedroom and closet doors were blown off their hinges. The stair rail was broken, and the interior plastered wall and ceiling finish were badly damaged.

3.3.8 One-story Precast Concrete House at 10,500 Ft (31.1-e2)

The measured overpressure at this location was approximately 1.7 psi (245 psf).

This house was a counterpart of the house described under Sec. 3.3.3. The building structurally withstood the blast in very good condition, and replacement of doors and windows could make it available for occupancy. (See Figs. 3.45 to 3.50.)

Only very minor structural damage was noted; some spalling of the concrete occurred at the lug connections. All glass in the front sash was blown in; some glass was blown out of other windows in side and rear walls; steel window sashes remained in place but were distorted in shape; and the Venetian blinds were blown across the rooms into a mass of rubbish. The exterior doors and the garage door were demolished.

3.3.9 One-story Concrete-block House at 10,500 Ft (31.1-f2)

The measured overpressure at this location was approximately 1.7 psi (245 psf).

This house was a counterpart of the house described under Sec. 3.3.4. The building structurally withstood the blast in excellent condition, and replacement of the doors and windows could make it available for occupancy. (See Figs. 3.51 and 3.52.)

There was no apparent damage to the structural parts of the building. The front door was blown across the room, and the rear door was broken at the lock. The glass in the front and side windows was blown in, and glass in the rear windows was blown out. The steel sash was warped and twisted but remained in place.

3.3.10 One-story Frame Rambler House at 10,500 Ft (31.1-c2)

The measured overpressure at this location was approximately 1.7 psi (245 psf).

This house was a counterpart of the house described under Sec. 3.3.2. Structurally the house did not suffer heavy damage (Figs. 3.53 to 3.55). A 2 by 4 in. stud located between the front door and window in the living room was cracked; the west side wall bulged out 4 in. at the ceiling line owing to lack of continuity of framing and the exterior siding split at the same line; the midspan rafter support beam on the front side was broken; and there was evidence of racking of the structure. Considerable damage was done to the plasterboard walls and ceilings. Glass in the front windows was sent flying; some glass was broken out of all the windows. The steel window sashes remained in place with only minor distortion. The steel Venetian blind from the front living-room window was blown through the rear window, smashing the glass. The front door was blown from its hinges across to the rear of the room. The porch roof was lifted 6 in. off its post supports. Many glass fragments were imbedded in the walls.

Fig. 3.1—Main FCDA test line, postshot, looking from GZ.

Fig. 3.2—Main FCDA test line, postshot, looking from middle distance toward GZ.

Fig. 3.3—Two-story brick house (31.1-a1) at 4700 ft, postshot.

Fig. 3.4—Two-story brick house (31.1-a1) at 4700 ft, postshot.

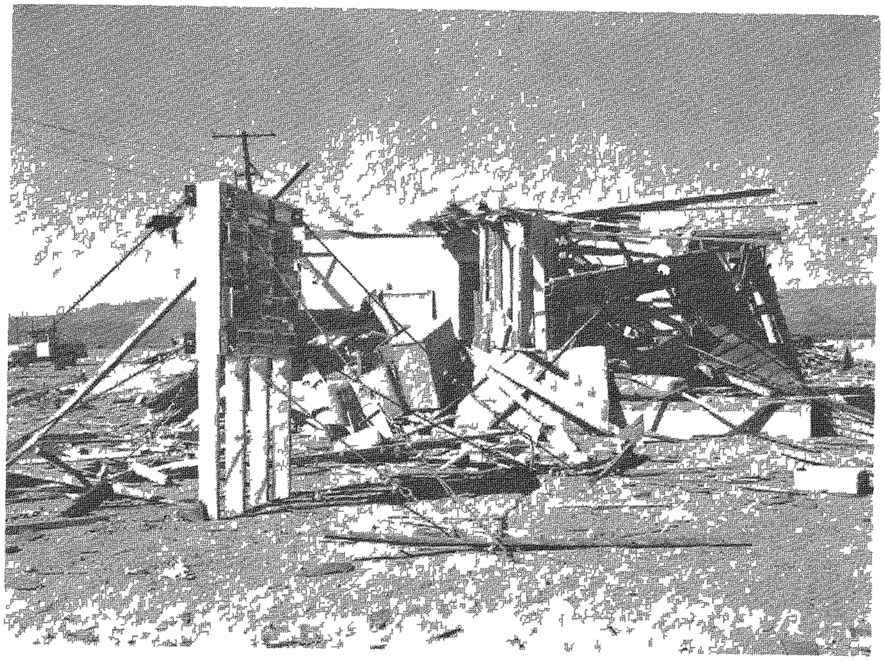


Fig. 3.5—One-story frame rambler house (31.1-c1) at 4700 ft, postshot.

Fig. 3.6—One-story frame rambler house (31.1-c1) at 4700 ft, postshot.

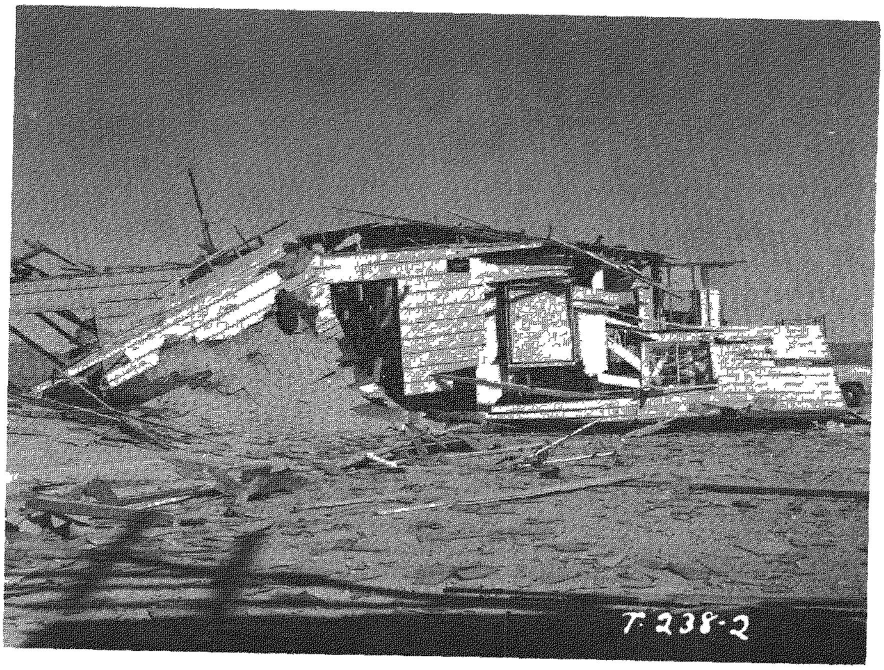


Fig. 3.7—One-story frame rambler house (31.1-c1) at 4700 ft, postshot, showing blast shutter and shelter undamaged.

Fig. 3.8—One-story frame rambler house (31.1-c1) at 4700 ft, postshot, showing the blast shutter opened and the window of the bathroom shelter.

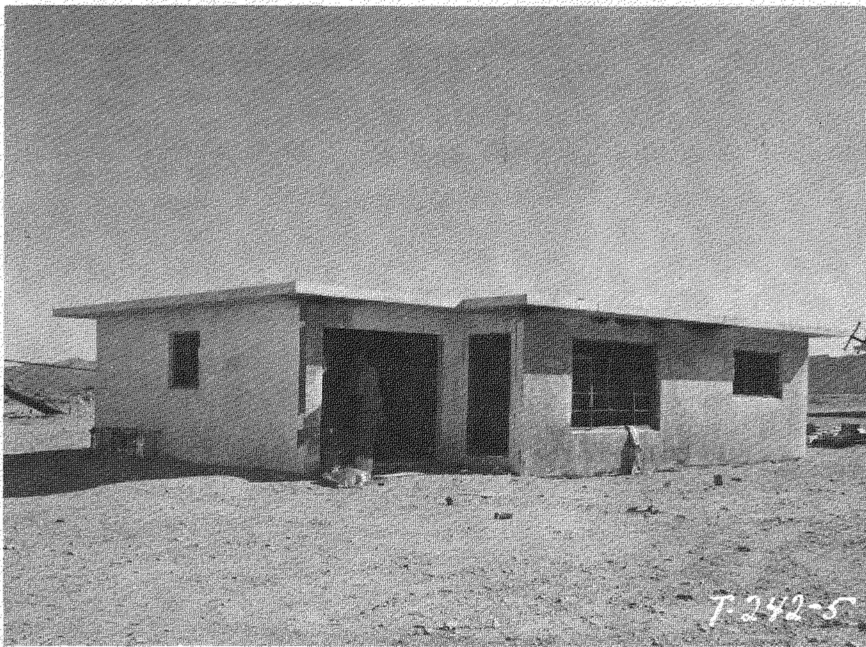


Fig. 3.9—One-story precast lightweight concrete house (31.1-e1) at 4700 ft, postshot.

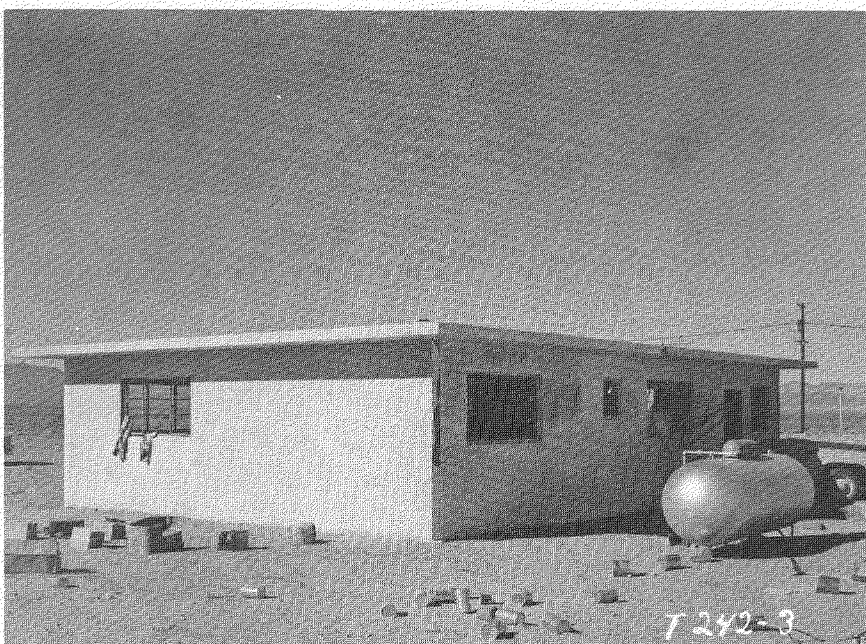


Fig. 3.10—One-story precast lightweight concrete house (31.1-e1) at 4700 ft, postshot.

Fig. 3.11—One-story precast lightweight concrete house (31.1-e1) at 4700 ft, postshot.

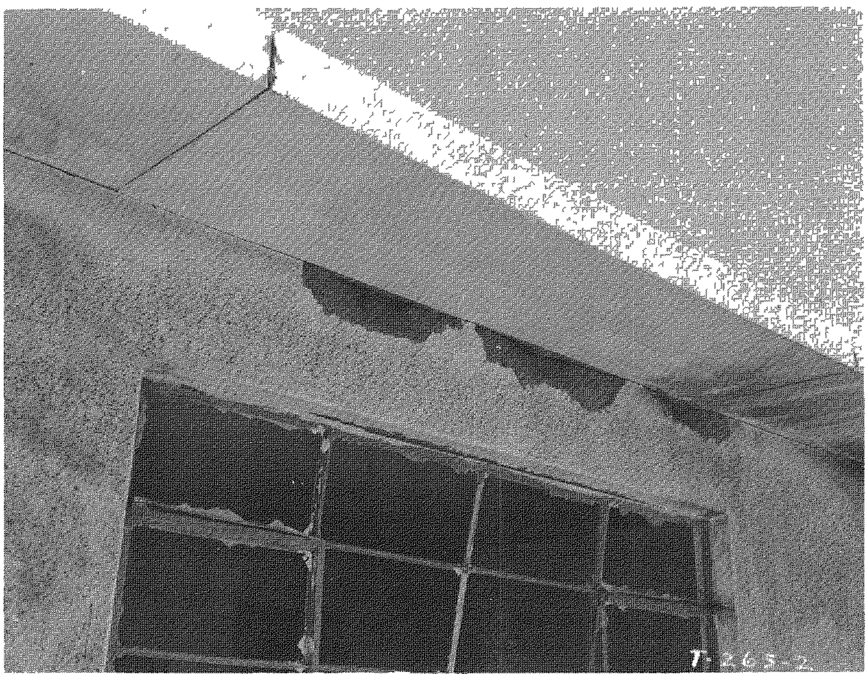


Fig. 3.12—One-story precast lightweight concrete house (31.1-e1), postshot, showing the spalling of the concrete on the front wall at the steel lug attachments due to lifting of the roof slab by the blast.

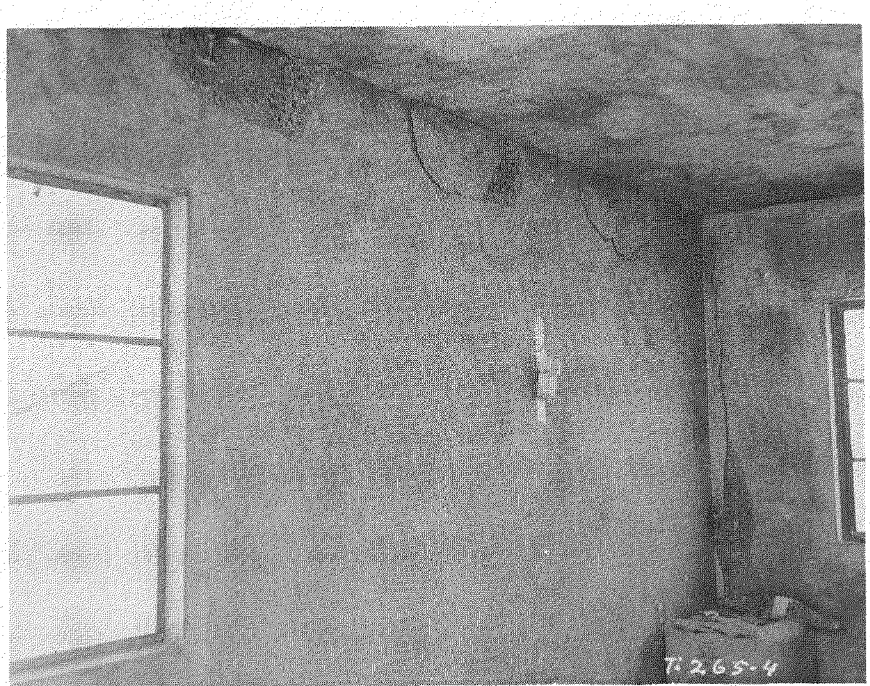


Fig. 3.13—One-story precast lightweight concrete house (31.1-e1), postshot, showing an interior view of spalling of the concrete at the connections of the wall to roof and wall to wall.

Fig. 3.14—One-story precast lightweight concrete house (31.1-e1) at 4700 ft, preshot. Interior view looking toward the kitchen in rear.

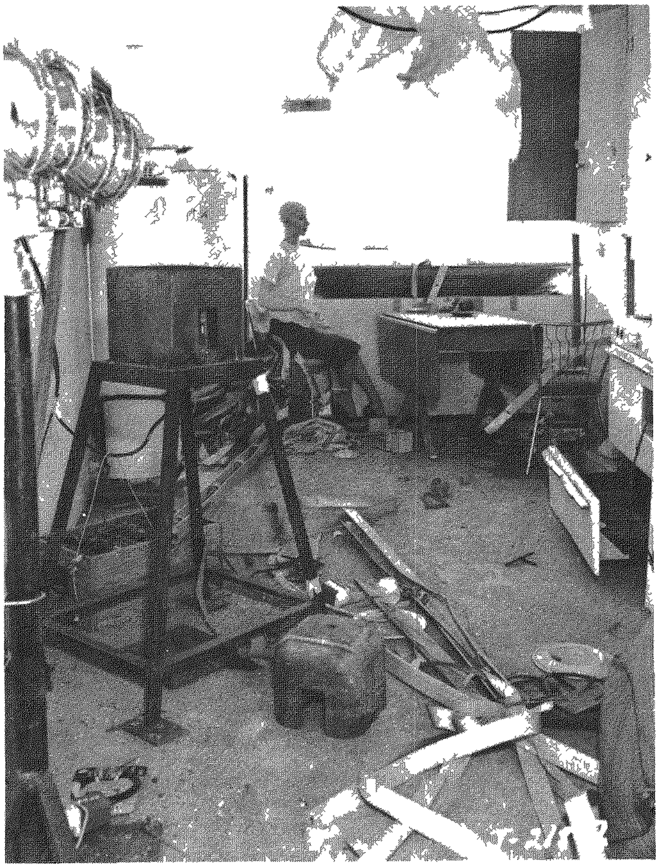


Fig. 3.15—The same view as that shown in Fig. 3.14, postshot.

Fig. 3.16—Fragments of the garage door on the precast lightweight concrete house (31.1-e1) at 4700 ft, postshot.

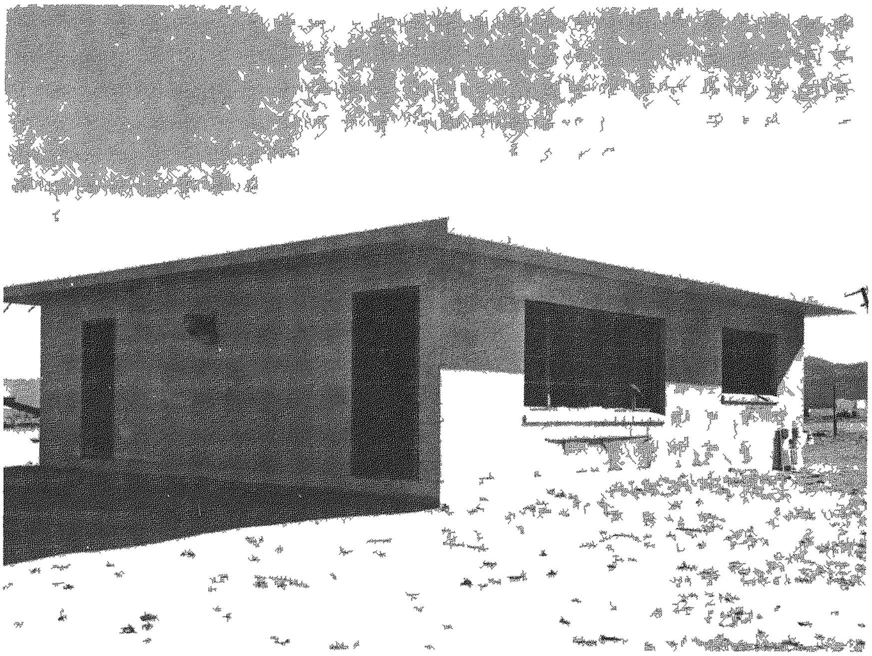


Fig. 3.17—One-story reinforced lightweight concrete-block house (31.1-f1) at 4700 ft, postshot.

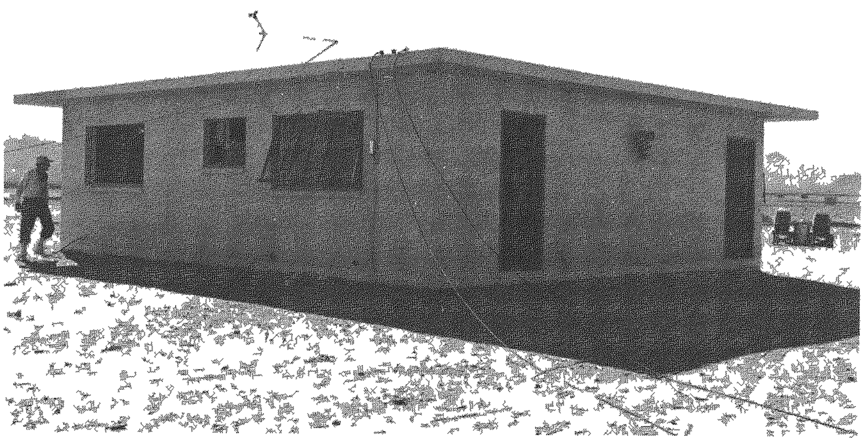


Fig. 3.18—One-story reinforced lightweight concrete-block house (31.1-f1) at 4700 ft, postshot.

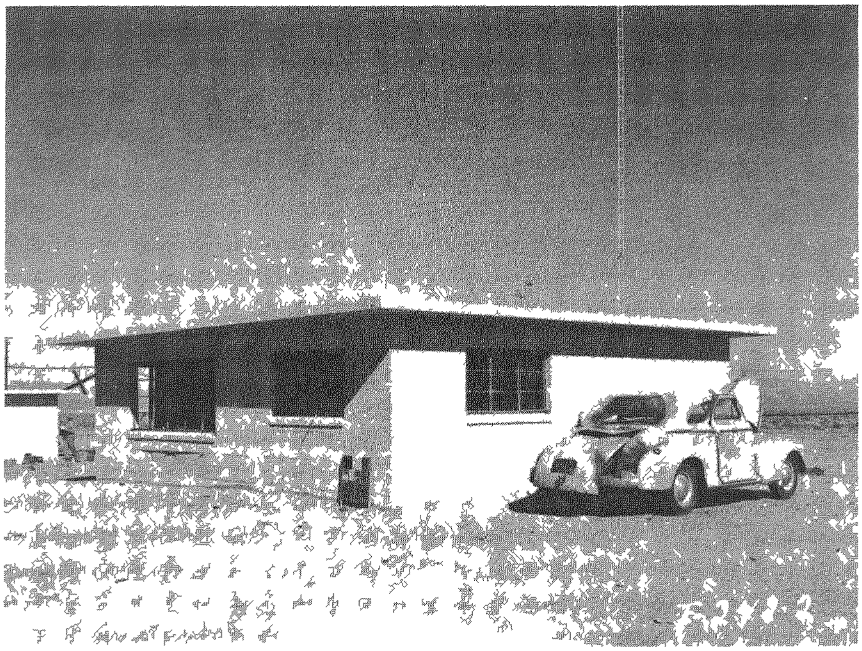


Fig. 3.19—One-story reinforced lightweight concrete-block house (31.1-f1) at 4700 ft, postshot.

Fig. 3.20—Damage under front window of one-story reinforced lightweight concrete-block house (31.1-f1) at 4700 ft, postshot.

Fig. 3.21—Two-story frame (strengthened) house (31.1-b1) at 5500 ft, postshot.

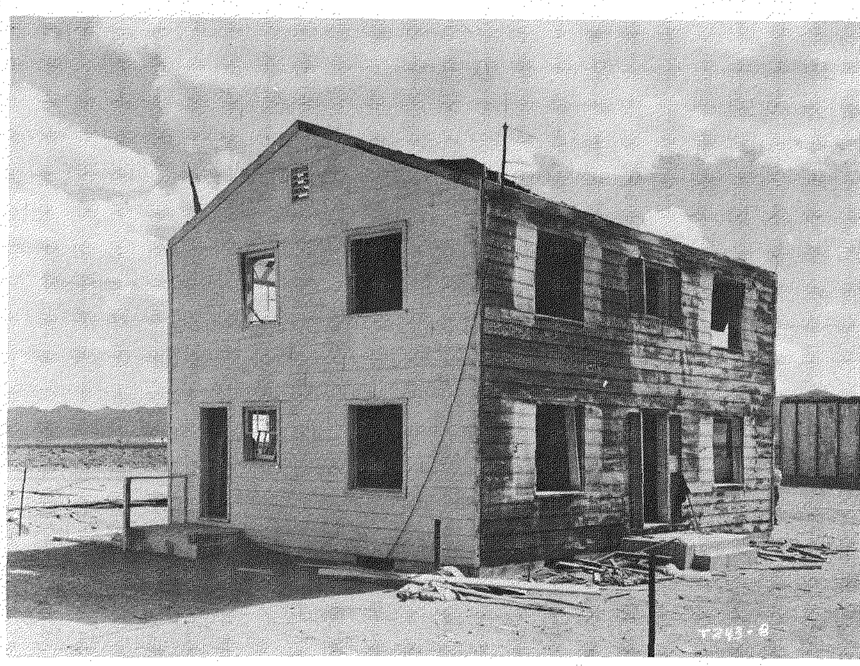


Fig. 3.22—Two-story frame (strengthened) house (31.1-b1) at 5500 ft, postshot.

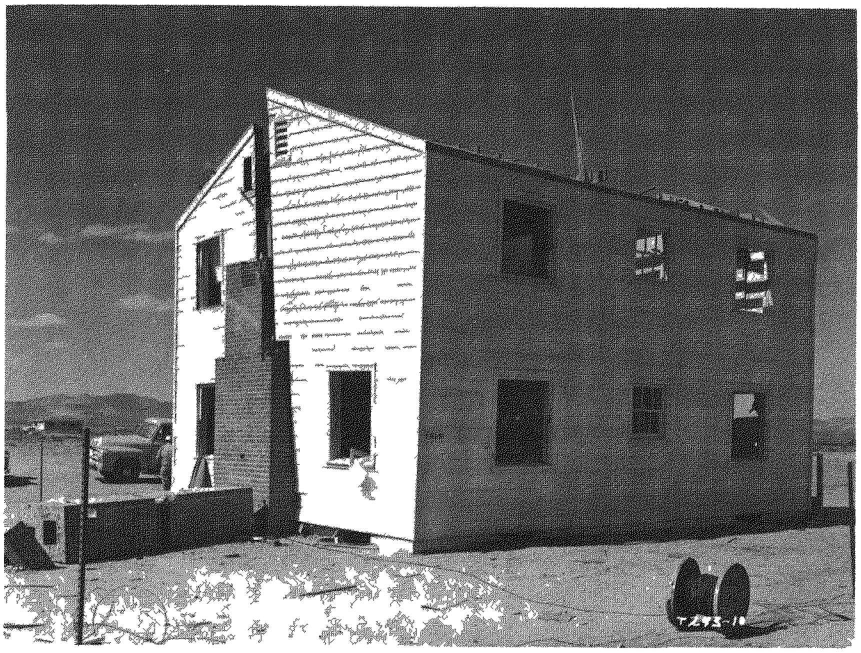


Fig. 3.23—Two-story frame (strengthened) house (31.1-b1) at 5500 ft, postshot.

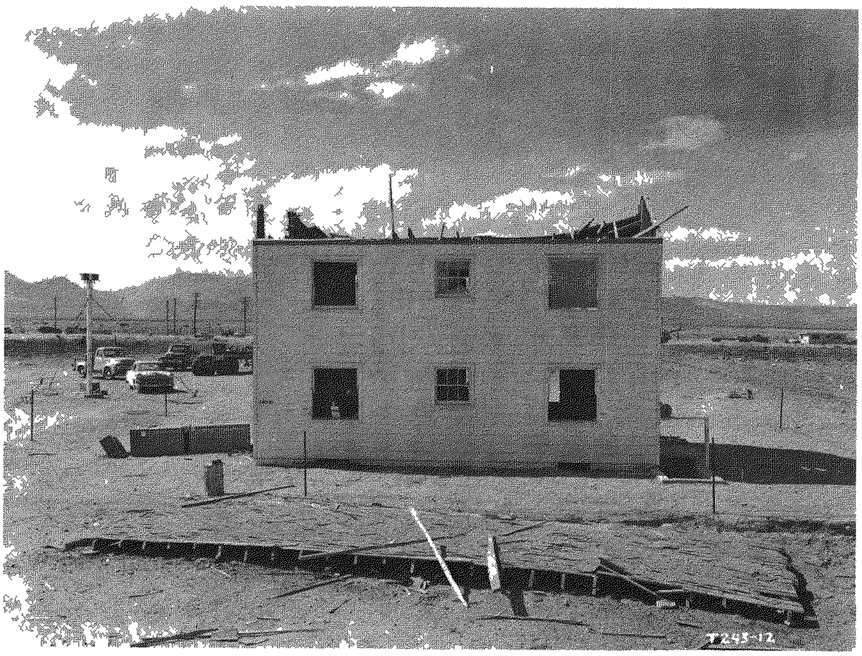


Fig. 3.24—Two-story frame (strengthened) house (31.1-b1) at 5500 ft, postshot.

Fig. 3.25—Looking toward rear of living room in the two-story frame house (31.1-b1) at 5500 ft, postshot. The exterior wall to rear of chimney bulged several inches and pulled away from floor framing. Note split hearth.

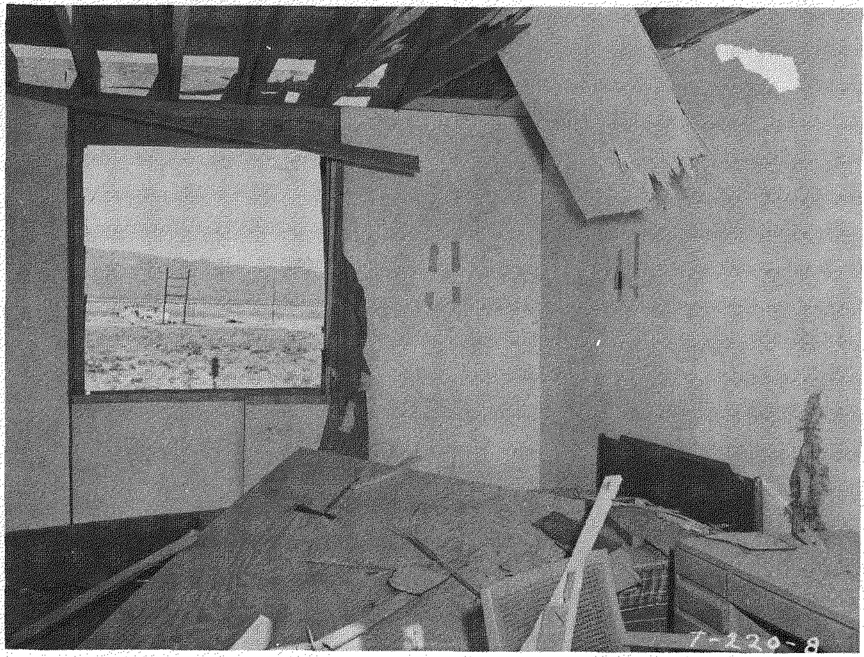


Fig. 3.26—Looking toward rear of master bedroom on second floor of two-story frame house (31.1-b1) at 5500 ft, postshot.

Fig. 3.27—First-floor framing under living room of the two-story frame house (31.1-b1) at 5500 ft, postshot.

Fig. 3.28—Stair to second floor of the two-story frame house (31.1-b1) at 5500 ft, postshot.

Fig. 3.29—Two-story frame house (31.1-b1) at 5500 ft, postshot, showing first-floor stair door to basement blown through plywood wall covering.

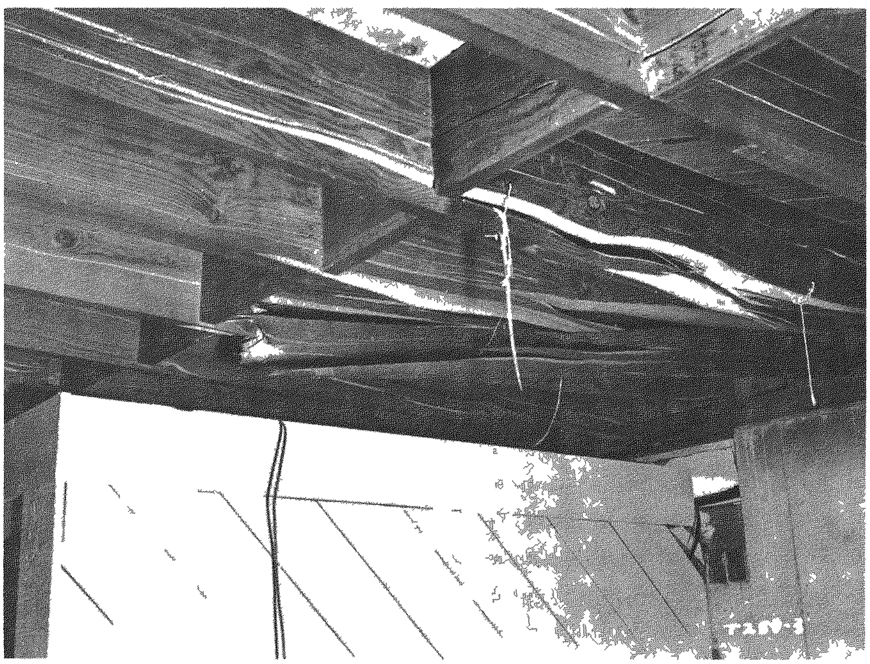


Fig. 3.30—First-floor framing under dining room of the two-story frame house (31.1-b1) at 5500 ft, postshot. Note solid bridging at midspan.

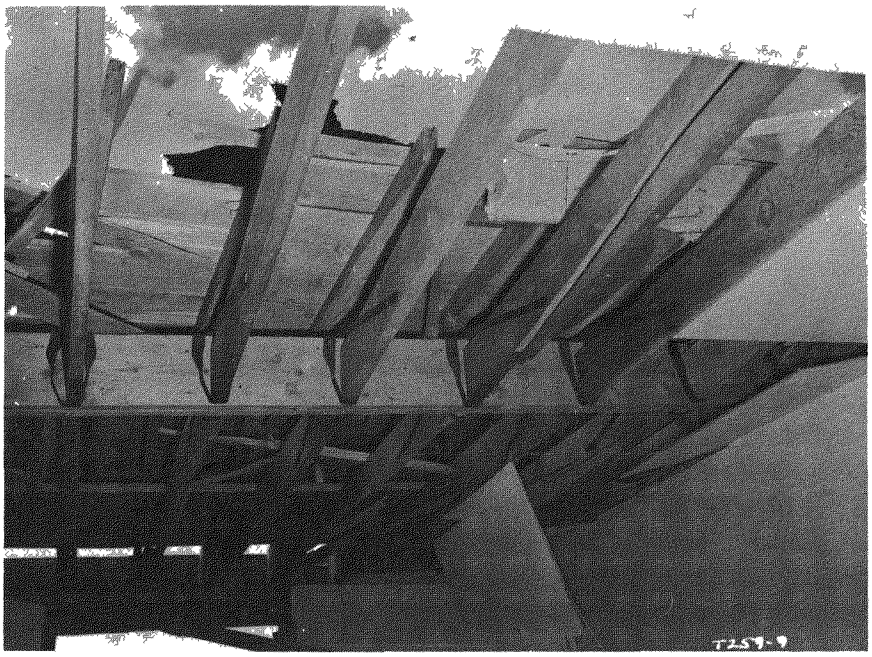


Fig. 3.31—Two-story frame (strengthened) house (31.1-b1) at 5500 ft, postshot, showing second-floor ceiling framing into center beam support in master bedroom. Note joists hangers and wrought-iron strap anchors installed over beam to lower edge of each abutting ceiling joist.

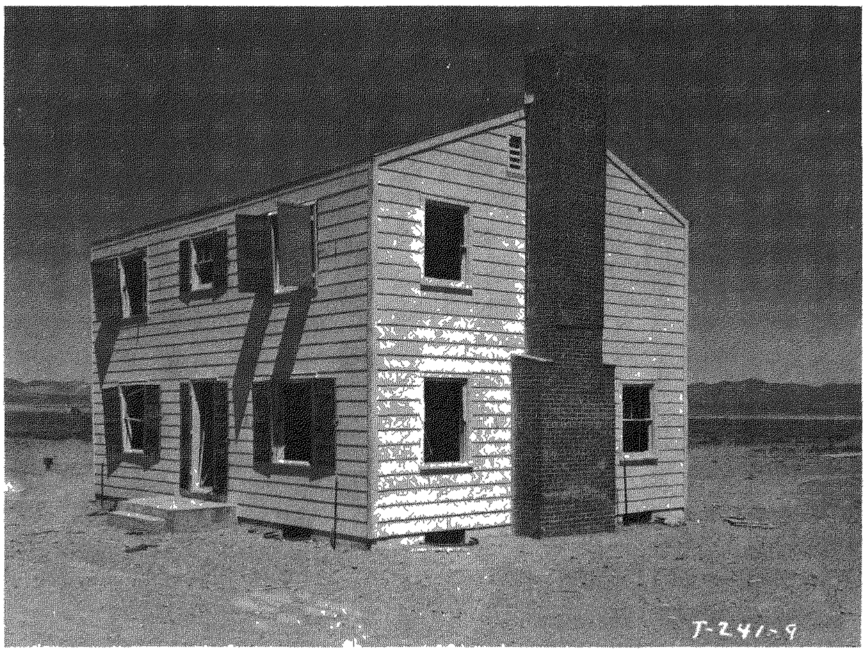


Fig. 3.32—Two-story frame (strengthened) house (31.1-b2) at 7800 ft, postshot.

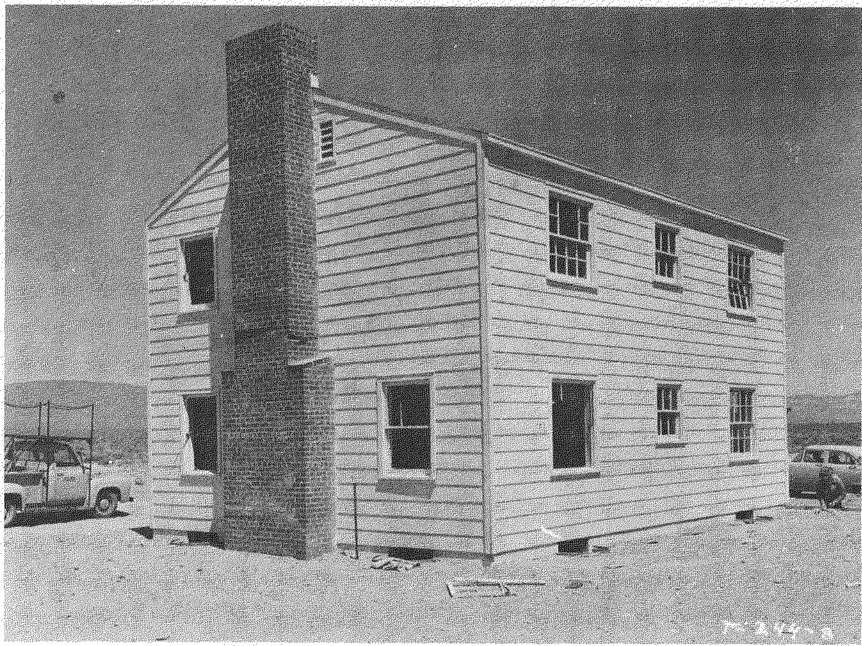


Fig. 3.33—Two-story frame (strengthened) house (31.1-b2) at 7800 ft, postshot.

Fig. 3.34—Living room of the two-story frame house (31.1-b2) at 7800 ft, postshot.

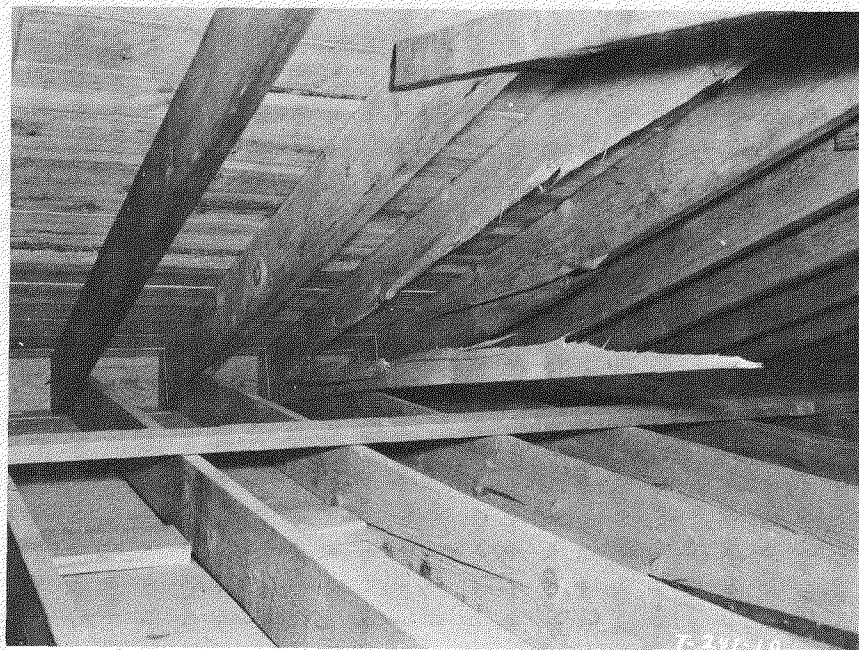


Fig. 3.35—Attic framing in the two-story frame house (31.1-b2) at 7800 ft, postshot.

Fig. 3.36—Strap iron joist ties over the center girder over the master bedroom in the two-story frame (strengthened) house (31.1-b2) at 7800 ft, postshot.

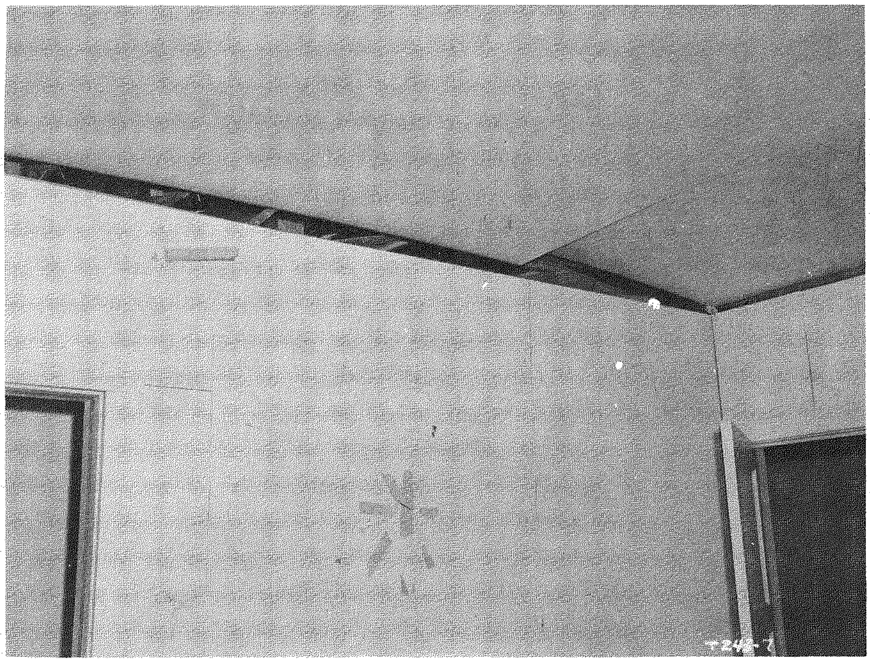


Fig. 3.37—Ceiling framing lifted from bearing and attachments to partition dividing front and rear bedrooms in the two-story frame house (31.1-b2) at 7800 ft, postshot.

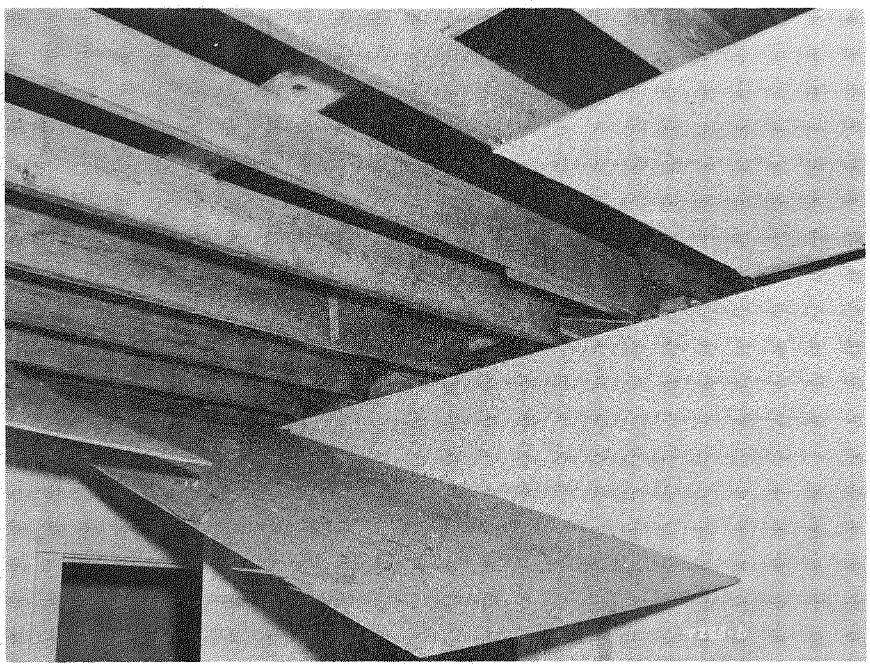


Fig. 3.38—Plywood ceiling covering blown down into second-floor bedroom in the two-story frame house (31.1-b2) at 7800 ft, postshot.

Fig. 3.39—First-floor framing in the two-story frame house (31.1-b2) at 7800 ft, postshot.

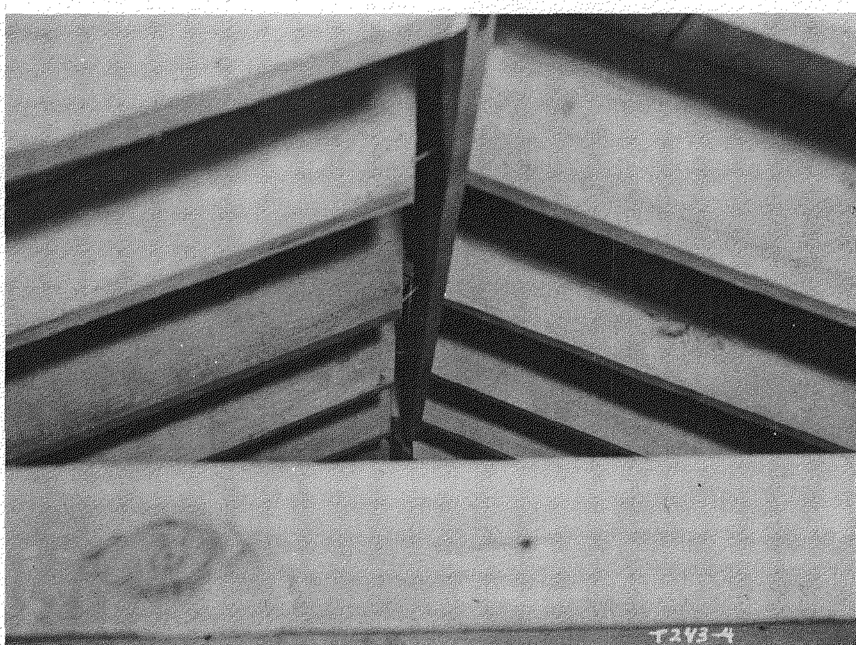


Fig. 3.40—Failure of the joint at the junction of the roof rafters and the ridge board in the two-story frame (strengthened) house (31.1-b2) at 7800 ft, postshot.

Fig. 3.41—Failure of the ridge board in the roof framing in the two-story frame (strengthened) house (31.1-b2) at 7800 ft, postshot.

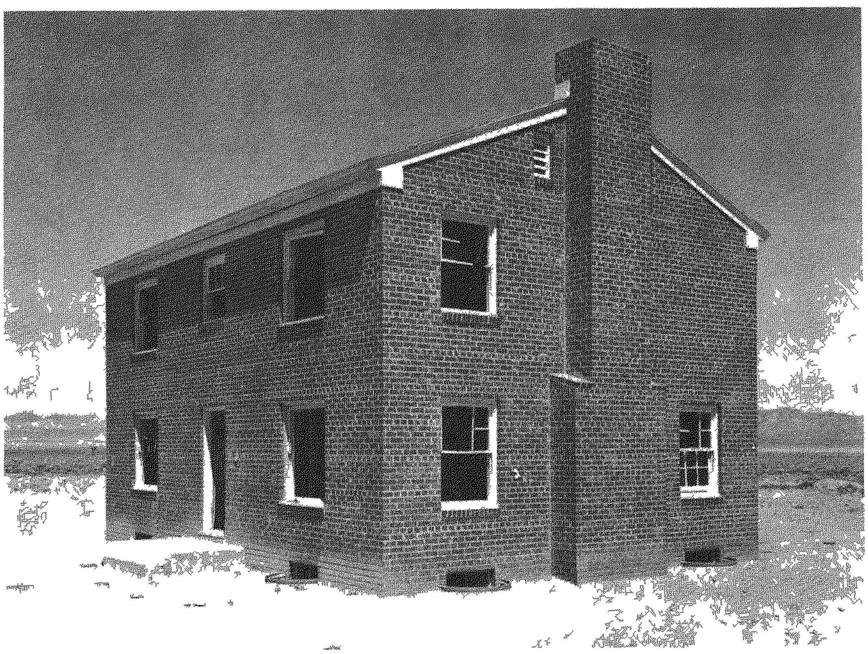


Fig. 3.42—Two story brick house (31.1-a2) at 10,500 ft, postshot.

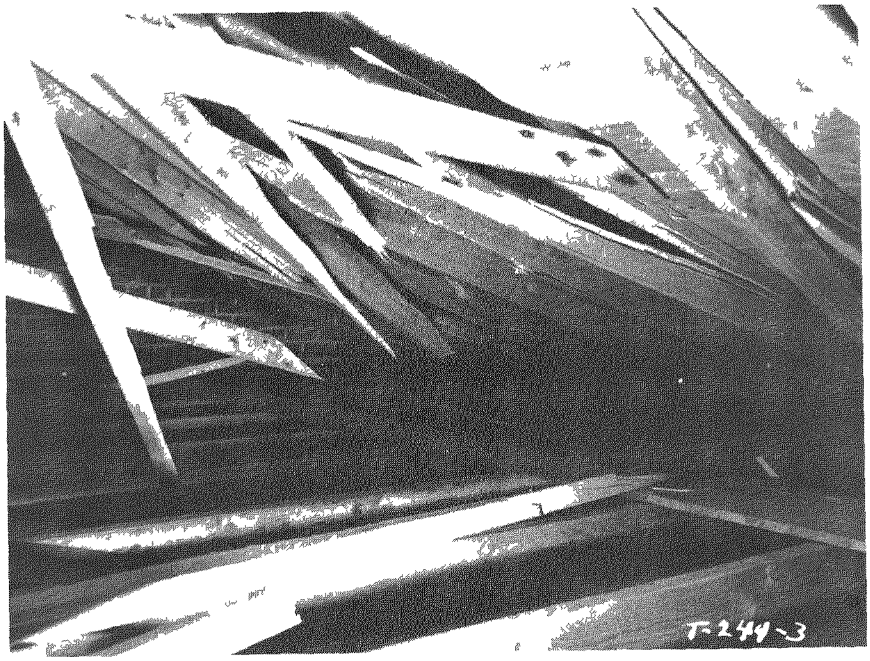


Fig. 3.43—Splintered rafters on front slope of roof of two-story brick house (31.1-a2) at 10,500 ft, postshot.

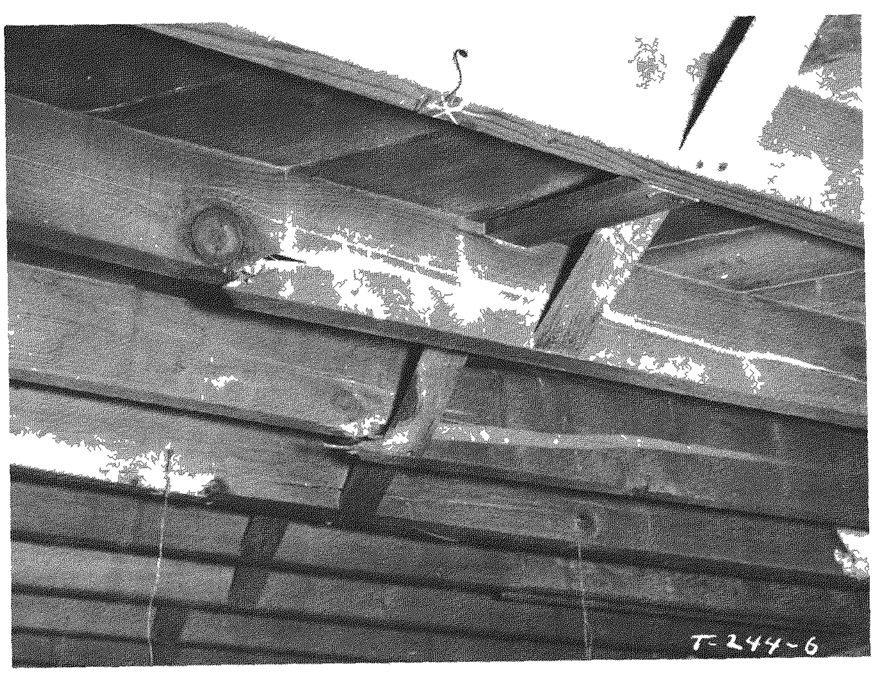


Fig. 3.44—Fractured first-floor joists under living room in two-story brick house (31.1-a2) at 10,500 ft, postshot.

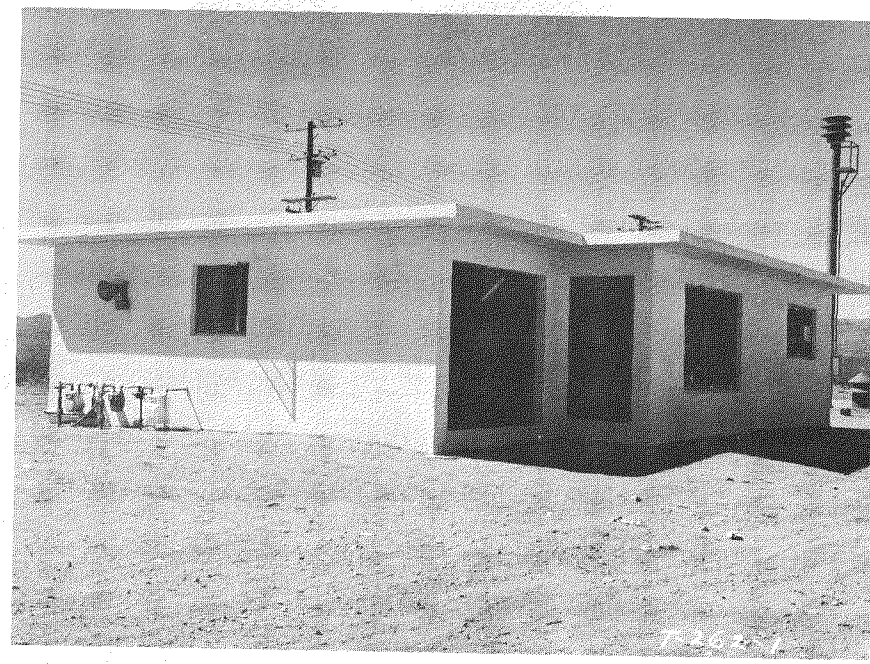


Fig. 3.45 — One-story precast lightweight concrete house (31.1-e2) at 10,500 ft, postshot.

Fig. 3.46 — One-story precast lightweight concrete house (31.1-e2) at 10,500 ft, postshot.

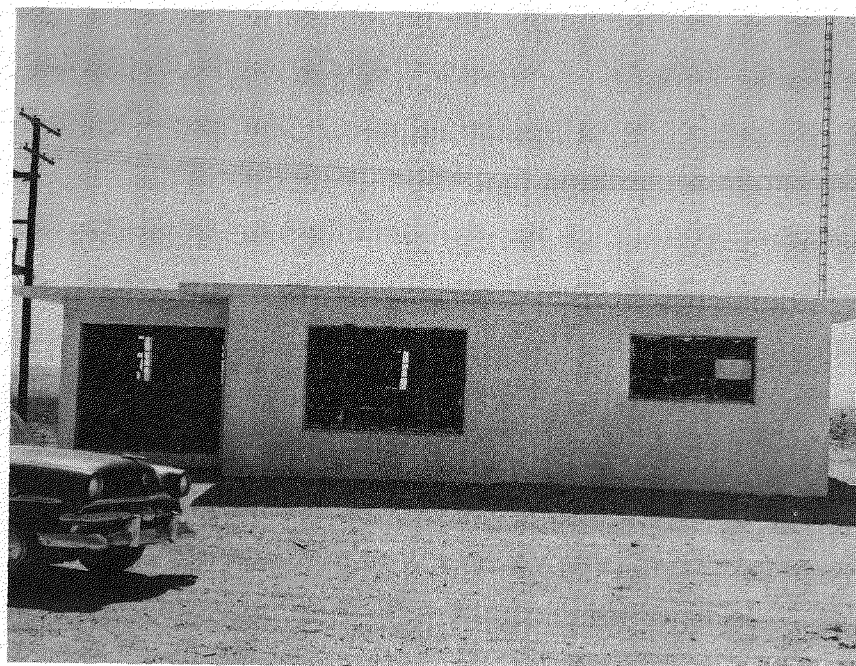


Fig. 3.47—One-story precast lightweight concrete house (31.1-e2) at 10,500 ft, postshot.

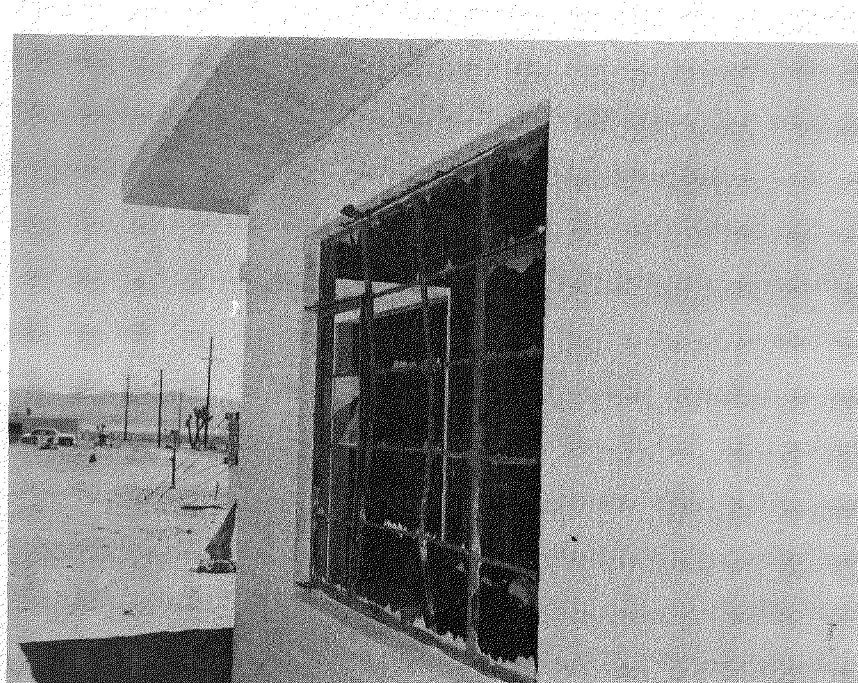


Fig. 3.48—Close-up of living-room window in one-story precast lightweight concrete house (31.1-e2) at 10,500 ft, postshot.

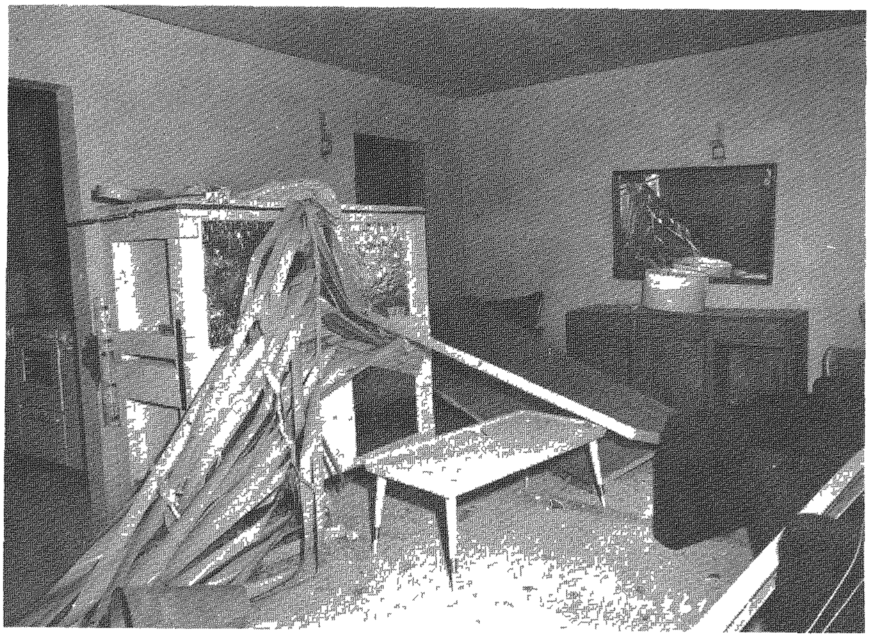


Fig. 3.49—Interior of one-story precast lightweight concrete house (31.1-e2) at 10,500 ft, postshot.

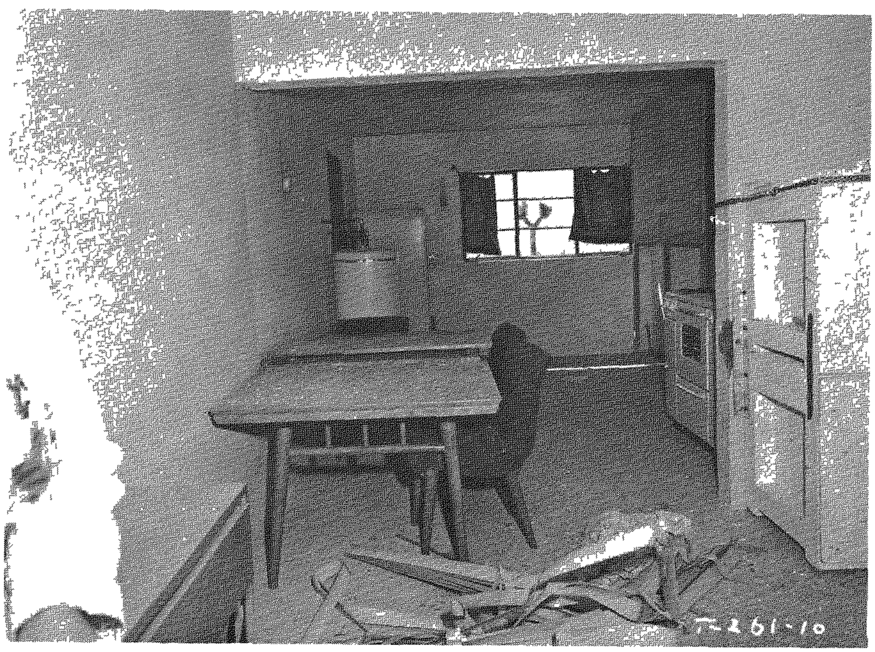


Fig. 3.50—Interior of one-story precast lightweight concrete house (31.1-e2) at 10,500 ft, postshot.

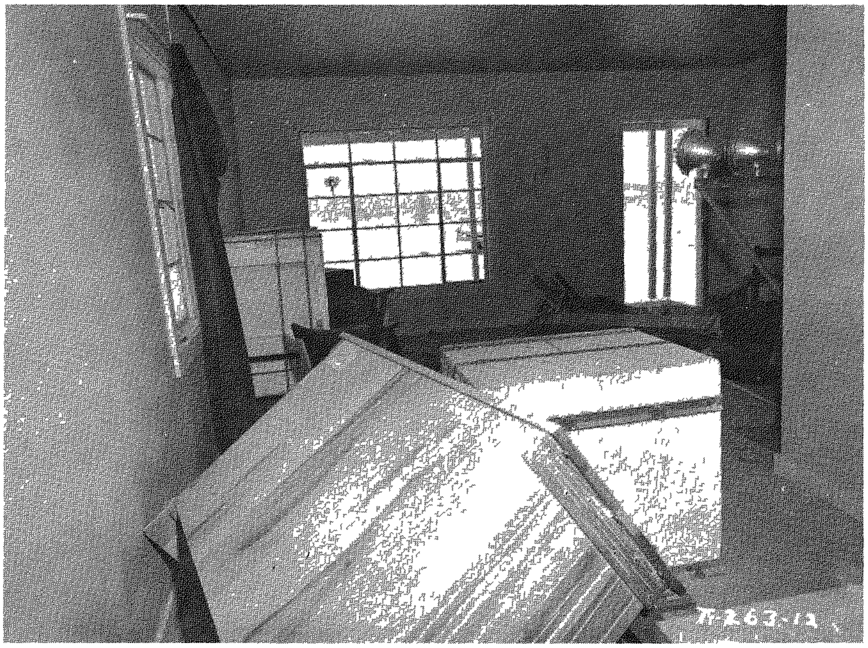


Fig. 3.51—Interior of one-story reinforced lightweight concrete-block house (31.1-f2) at 10,500 ft, postshot.

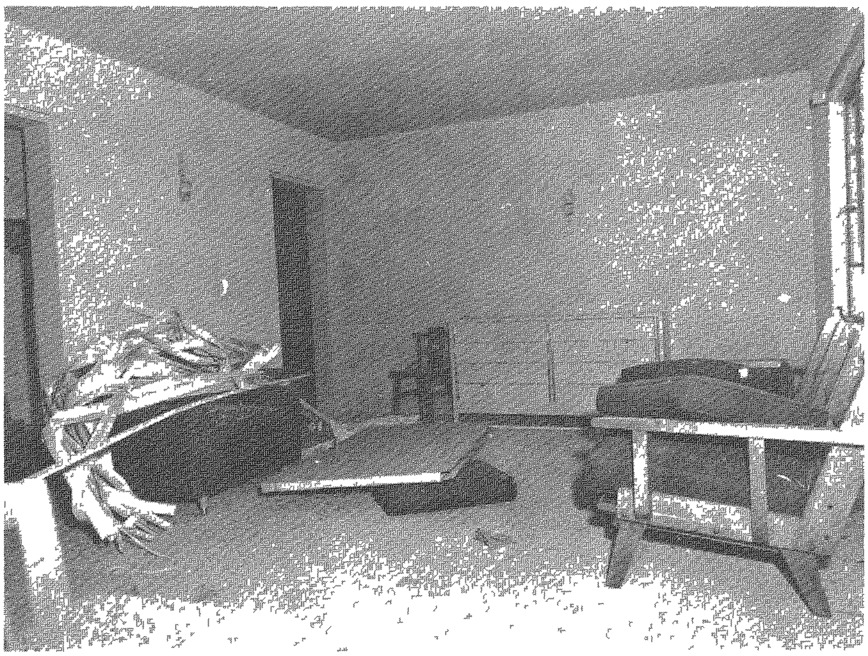


Fig. 3.52—Interior of one-story reinforced lightweight concrete-block house (31.1-f2) at 10,500 ft, postshot.

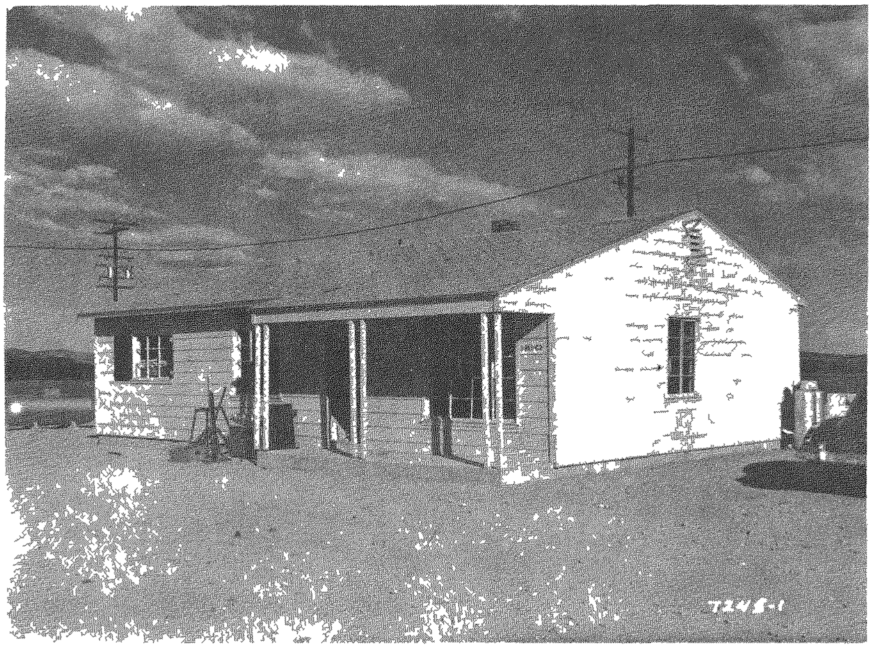


Fig. 3.53—One-story frame rambler house (31.1-c2) at 10,500 ft, postshot.

Fig. 3.54—One-story frame rambler house (31.1-c2) at 10,500 ft, postshot.

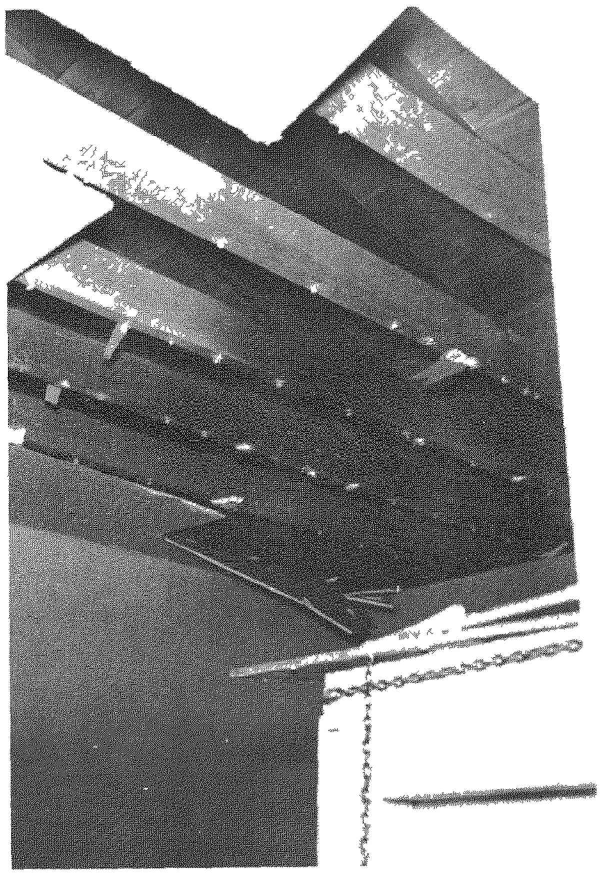


Fig. 3.55—Ceiling material blown down by blast in one-story frame rambler house (31.1-c2) at 10,500 ft, postshot.

Chapter 4

DISCUSSION

4.1 ANALYSIS OF GAMMA-RADIATION DATA

Analysis of the data on gamma radiation is presented in Operation Teapot Report WT-1174.

4.2 ANALYSIS OF THERMAL-RADIATION EFFECTS DATA

A study of motion pictures of the houses taken during the event indicates that there was no free-flaming or burning of the buildings nor any fire damage as a result of thermal radiation. However, the white-painted exterior woodwork of the two-story brick and cinder-block house (31.1-a1) and the yellow-painted one-story frame rambler house (31.1-c1) on the 4700 ft line showed evidence of charring to depths of not more than $1/64$ to $1/32$ of an inch. Charring occurred also on the front face of the two-story frame house (31.1-b1) on the 5500-ft line (see Figs. 3.21 and 3.22). The white paint on the frame house (31.1-b2) at the 7800-ft range seemed to provide sufficient reflective surface to prevent scorching of the wood siding, but the light gray paint on the shutters apparently absorbed enough thermal radiation to cause slight scorching of the shutters. Effects of thermal radiation were limited to the faces of walls and shutters on the house side exposed to GZ.

The thermal-radiation impulse from the explosion, traveling at approximately the speed of light, caused scorching and some charring on the faces of the nearer houses and the emission of smoke without visible or free flaming. Smoke was lifted up the face of the houses, including those of painted concrete, apparently by convection currents and not by the blast since the effects of the thermal wave were over and the houses were practically free of smoke before the blast wave arrived.

The light-colored paints used on the exterior woodwork of the houses seemed to serve their purpose by reflecting the heat wave to some extent and minimizing the possibilities of ignition. Equally effective in preventing thermal radiation from entering the houses and causing fires by ignition of draperies, furniture, etc., was the use of Venetian blinds on the windows facing the blast and of white opaque coatings on the glass.

The duration of the thermal radiation in this test appeared to be very brief and insufficient in duration to build up enough heat in the combustible materials to cause free flaming.

4.3 ANALYSIS OF BLAST EFFECTS DATA

In studying and analyzing the effects of the nuclear blast on the residential structures included in this test, one must recognize that the overpressures developed by the size of the device exploded, the distance of the structures from GZ, and the amount of shielding benefiting the structures will determine the economic feasibility of constructing houses strong enough to offer reasonable protection to the inhabitants from blast effects. The most that can be hoped for is to so strengthen the houses at a reasonable expenditure of money above normal construction costs that those housing structures in the periphery of a blast area will remain in rehabilitable condition with a minimum expenditure of funds. For comparison, housing in areas of the country subject to hurricane winds of up to 120 mph are designed to resist pressures that would represent an overpressure of approximately 0.25 psi (37 psf) on the wall surfaces as compared to overpressures on the test houses of up to 735 psf. Similarly, in areas subject to earthquakes, dwelling structures are designed to resist the resulting stresses. However, examination of the test dwellings postshot would indicate that stresses and pressures developed by wind conditions would more closely parallel conditions developed by nuclear blast. Basements of the test houses were not affected by the nuclear explosion. Only those portions of the structures aboveground appeared to be affected by the blast, indicating minimum earth pressures from a nuclear blast aboveground.

It was known long before these tests were undertaken that a low wall has greater resistance to lateral pressure than a high wall of the same material and cross-section and that a steel-reinforced wall is stronger and has more resistance to lateral pressure than a similar unreinforced wall. Also, an axially loaded masonry wall develops greater resistance to lateral load than an axially unloaded wall. If vertical and horizontal steel reinforcing had been installed in the two-story brick house (31.1-a1), its resistance to destruction would presumably have been much superior. Had the one-story concrete-block house (31.1-f1) not been reinforced and heavily loaded with the precast concrete roof slabs, it is probable that greater damage would have occurred to the structure as indicated by the damage suffered by the unreinforced wall under the large window.

It should be kept in mind also in studying the effects of the blast that these tests were designed to reveal gross effects of the blast on the distinctively different types of individual structures and were not intended as comparative tests of different types of materials used in construction. The materials used in the construction of the structures should not be compared for blast-resistant properties on the basis of whether one structure failed and another structure did not. Much depends on how the materials are used in the design. For example, in studying the effects of the blast on the one-story reinforced-concrete block house (31.1-f1) vs. the two-story brick house (31.1-a1) the results of these tests do not indicate in any way that concrete block, as a building material, should be considered superior to brick or vice versa. Architectural design also would have considerable effect upon the behavior of a dwelling subjected to nuclear forces. For example, the modern trend toward large windows permits a more rapid equalization of pressure within and outside a building through the blowing out of the window areas; at the same time it could increase the danger to occupants of the houses from flying fragments of glass. A flat roof offers much less exposure to wind pressures than a gable roof and a small projection of the roof over the walls likewise offers less exposure than would be provided by the large overhanging roof favored in a one-story modern dwelling construction. There are many additional factors that might affect the resistance of a structure to lateral blast loads, such as the geometry of the structures, the ratio of window and door openings to total wall area, and the design of floors and interior partitions.

Motion pictures of the blast effects on the two-story brick house (31.1-a1) showed that the second-floor construction offered considerable resistance to the wind forces against the building. However, when the initial blast wave had passed the house and the pressure had built up within the structure to a level greater than the exterior pressure, the structure exploded. The use of fire cuts on the second-floor joists, designed to reduce damage to the exterior walls should the interior bearing of the joists be destroyed by fire within the structure, provided minimum anchorage to the exterior walls and offered only slight resistance to the explosive effects of the higher pressure within the structure. As seen in the motion pictures, the two-story brick house (31.1-a1) appeared to literally blow apart from the pressure built up within the structure during the high-pressure portion of the positive phase of the blast wave.

In general, both the one-story precast concrete house (31.1-e1) and the one-story concrete-block house (31.1-f1) structurally withstood the effects of the blast very well; the weakening of the connections between the walls and roof sections was the most apparent damage.

In each of the four two-story houses (31.1-a1, 31.1-a2, 31.1-b1, and 31.1-b2) the wooden roof framing showed similar characteristics of lack of strength to resist blast effects. Weakness developed in the connections of the roof rafters to the ridge board. This connection is ordinarily designed to resist compressive forces applied externally but not to resist high pressures developed in the attic space, which tend to exert explosive force within the attic, breaking the connection of the roof sections at the ridge and plate, lifting the rear roof section, and blowing it well to the rear of the house.

Notwithstanding the strengthening of the roof rafters (from 2 by 6 in. in the 1953 experiment house, which failed when subjected to an overpressure of approximately 245 psf, to 2 by 10 in. rafters in the 1955 experiment houses (31.1-b1 and 31.1-b2), which were subjected to overpressures of approximately 576 psf and 375 psf, respectively), many of the roof rafters were broken, the ridge connections were demolished or badly split, and, in the house (31.1-b1) subjected to 576 psf overpressure, the connection of the roof section to the wall plate was destroyed.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Owing to differences in the overpressures to which the houses were subjected, no direct comparison can be made between the effectiveness of the strengthening devices used in the two-story frame houses (31.1-b1 and 31.1-b2) and the frame house used in the 1953 experiment (1.7 psi or 245 psf overpressure in the 1953 experiment house, 2.6 psi or 375 psf overpressure in house 31.1-b2, and 4.1 psi or 576 psf overpressure in house 31.1-b1). However, some general observations as to the effectiveness of the strengthening devices can be made.

Although the first-floor framing in house 31.1-b1 failed when subjected to 576 psf overpressure, the destructive effect of the 375-psf overpressure on the first-floor construction of house 31.1-b2 was not so apparent as the effect of 245-psf overpressure on the unstrengthened 1953 test house. The exterior walls of both two-story frame houses (31.1-b1 and 31.1-b2) showed minimum structural damage except to the side wall of house 31.1-b1, where the continuity of wall framing was broken by the construction of the masonry chimney. The increased number of nails per connection and the use of special grooved nails is believed to have given greater holding power to the various connections. However, analysis of the data gathered in this test and visual observations indicate that joints, connections, and fastenings were the weakest structural elements in conventional construction in resistance to nuclear blast forces.

These weaknesses were manifested in the broken connections between the ridge and roof rafters and the connections of the roof elements to the walls; in the loosening of the lug connections in the precast concrete house and the reinforced-concrete-block house; in the release of the masonry walls from the floor system in the brick house; in the broken connections and lifting of the roofs from the walls, ceilings from partitions, and joists from their hangers; in the pulling away of broken joists from the subflooring (with surprisingly little residual deflection remaining in the sub and finish flooring); and in the release of much of the plywood interior along its nailing edge.

Because more adequate connections between elements of the structure can be provided at a moderate increase in cost, it is believed that any future tests should include test houses with improved connections.

Many of the failures of joists, rafters, and studs occurred at points where large knots or steep cross-grain were located at the bottom edge or on the tension side of the wood members. Performance of these members would have been improved if the better edge of the joists and rafters had been placed downward.

5.2 RECOMMENDATIONS

To provide increased protection of dwelling structures that might be endangered by nuclear blast and, at the same time, keep the cost of such added protection to a minimum, the following suggestions are submitted:

Provide better anchorage of the roof rafters to the wall plate by the use of sheet metal or strap-iron anchors.

Install a heavier ridge member in the roof framing, perhaps a nominal 2-in.-thick member in lieu of a 1-in. member.

Install wood or plywood gusset plates in the roof framing tying the roof rafters together at the ridge or install sheet-metal strap anchors in the roof framing tying the roof rafters together at the ridge.

Provide a continuous support or purlin at the midspan of the roof rafters, tied back to a center supporting partition or girder. It is believed that such a support would be more effective in strengthening the roof than increasing rafter sizes.

The strengthening of the exterior-wall framing by the use of 2 by 6 in. studs in lieu of 2 by 4 in. studs and the use of ballon framing in lieu of platform framing appeared justified by the resistance of the walls to the blast.

Where chimneys and/or fireplaces are constructed on outside frame walls of residential structures, care should be taken that continuity of the frame wall construction is not broken. In the two-story wood frame house subjected to an overpressure of 4.0 psi (576 psf), the frame end wall containing the chimney failed to give satisfactory performance owing to the break in continuity of framing.

Generally, the second-floor framing in a two-story house, where the wall support of the floor framing was not destroyed, survived the blast very successfully because the windows and doors blew out and there was a rapid equalization of overpressures above and below the floor construction. It is therefore suggested that larger and more adequate louvers or windows be provided in the attics of houses to permit a more rapid equalization of the air pressure in the attic with the outside pressure.

In order to minimize blast damage to property, more window surface should be provided in basements to assist in permitting equalization of overpressures above and below the first-floor construction.

Although the concrete shear walls in the basements of the two-story frame houses were effective in resisting movement of the first-floor construction, the resistance of the girders and lally columns in the basement of the two-story brick house to movement under the overpressure of 5.1 psi (735 psf) indicates that such walls may not be necessary if the first-floor framing system is adequately anchored to the basement walls and the basement walls are properly designed and constructed.

Basements in the houses were found to provide considerable protection as refuge areas, except for the failure of first-floor joists. The diaphragmatic action of the sub and finish floor, even where joists pulled away from the subflooring, provided a certain amount of protection from debris falling from above. The greatest danger occurred from the failure of the floor joists at approximately the midspan and the splintering and splitting of the joists. These joists could be strengthened considerably at low cost by rearrangement of girders and basement columns to reduce the joist span.

Appendix A

NAILING SCHEDULE

SCHEDULE A.1 (FRAME DWELLING)

Joints in the frame dwelling should be securely nailed with common nails conforming to the requirements of Federal Specification FF-N-101, with the number of nails per joint and the size of such nails to be in accordance with common practice. The recommended nail spacing for a particular joint is as indicated below:

1st floor, joist ends to sill (toenail two each side, staggered)	4–3½ in.
1st floor, 1st and last joist to sill (toenail two between each stud each side of joist, staggered)	3½ in.
1st floor, joists to studs at side walls (three each side staggered)	6–3½ in.
1st floor, joists to studs at front and rear walls (from inside face nailed)	3–3½ in.
1st floor, studs to sill (toenail from each face staggered, three one face, two other face)	5–3½ in.
1st floor, corner bracer between first two joists (three each end)	6–3½ in.
1st floor, nailer to joist (toenail)	2–3½ in.
1st floor, nailer to studs (face nail)	2–3½ in.
1st floor, blocking to joists (three end nailed at each end)	6–3½ in.
1st floor, ¾-in. plywood plate at sill, through filler to joists, top and bottom row, three each, middle row four; to sill four, each nail slanted in different direction	14–2½ in.
1st floor, joists to girders (toenail, each joist)	2–3½ in.
1st floor, joist to studs at center-bearing walls, three each side	6–3½ in.
1st floor, studs (2 by 4's at center-bearing wall) to girder, toenail, two one side	2–3½ in.
2nd floor, joists to studs in all exterior walls	3–3½ in.
2nd floor, joists to studs (2 by 4's at center-bearing wall) two each side	4–3½ in.
2nd floor, blocking (end nail at each end)	2–3½ in.
Headers in 6-in. walls:	
Nail center piece to one outside piece, on 2-ft 0-in. centers	3 in.
Nail outside piece to inside piece, on 6-in. centers	4 in.
End nail each piece to studs	2–3½ in.
Headers in 4-in. walls:	
Nail both sides on 6-in. centers	3½ in.
End nail each piece to studs	2–3½ in.
Top plates:	
Lower piece of plate to each 6-in. stud	3–3½ in.

Lower piece of plate to each 4-in. stud	2–3½ in.
Upper piece of plate to lower piece nailed from face of each piece, on 12-in. centers, staggered	3 in.
Rafters to plate on side away from ceiling joist	2–3½ in.
Rafters to ceiling joists, cleated three one side, two other side	5–4 in.
Ceiling joist to plate, toenail two from one side, one other side	3–3½ in.
Continuous closure piece:	
Into rafter slanted	3–3 in.
Into ceiling joists	3–3 in.
Into each piece of plate, staggered on 16-in. centers	3 in.
Corner posts:	
Toenail each exposed face to sill as post is assembled	2–3½ in.
Stud to stud on 12-in. centers, staggered	3½ in.
Each stud to filler block on 6-in. centers, staggered	3½ in.
2 by 4 nailer to stud on 16-in centers	3½ in.
Joist end to joist end at laps:	
2 by 10 joists, three from one side, two from other side	5–3 in.
2 by 8 joists, two from one side, two from other side	4–3 in.
Ribbons (1 by 6 in.) into studs	2–2½ in.
Sheathing (1 by 8 in. or less) to each bearing	2–2½ in.
Exterior wood siding to each stud	3–2½ in.
Other joints and nailing applications, nail to provide proportionate strength	

NOTE: Wherever possible, when flat pieces are nailed, slant the nails slightly in different directions to prevent easy withdrawal.

SCHEDULE A.2 (BRICK DWELLING)

Joints in the brick dwelling should be securely nailed with common nails conforming to the requirements of Federal Specification FF-N-101, with the number of nails per joint and the size of such nails to be in accordance with common practice. The recommended nail spacing for a particular joint is as indicated below:

Joist to sill or girders, toenail	3½ in.
Cross bridging to joists, toenail each end	2½ in.
1 by 8-in. subfloor to joist, face nail	2½ in.
Joist or blocking to sole plate on 16-in. centers	4 in.
Top plate to stud, end nail	3½ in.
Stud to sill, toenail	3½ in.
Double studs and joists on 30-in. centers	3½ in.
Top plates, spiked together on 24-in. centers	3½ in.
laps and intersections	3½ in.
to parallel rafters	3½ in.
to ceiling joists	3½ in.
Rafter to plate	3½ in.
Rafter to ceiling joist	4 in.
Rafter to center board (one in top, one each side)	2½ in.
1 by 8-in. sheathing, or less, to bearing	2½ in.
Exterior siding, 10-in. material	2½ in.
Corner stud	2½ in.
Other joints, nail to provide proportionate strength	