velocity from the southwest. Except in Nagasaki where the fires swept up the hills on both sides of the Urakami Valley, there was no evidence of a general advancing front to the conflagration in either city. At Hiroshima, however, there was some fire spread beyond 5,000 feet from Ground Zero in built-up areas outside the periphery of the original fires. A large proportion of the burned-over areas in both cities resulted from the spreading and merging of the original fires. In Hiroshima most of the fire had burned itself out or had been extinguished in the fringe area about 12 hours after the explosion. In Nagasaki most of the fires had died out or were under control about 19 hours after the explosion. Isolated fires continued to burn, and smoldering persisted over a large part of the burned-over areas in the two cities for three or four days. In fact, grain in three warehouses in Hiroshima burned for several weeks.

5. Fire Fighting

a. Effort. Almost no effort was made to fight the conflagrations within the areas finally burned over except in a few reinforced-concrete buildings where the occupants remained or where people took refuge. At Hiroshima the fire wind blowing toward the city from all directions was a major factor in checking fire spread at the perimeter. In both cities, the more sparsely built-up areas, some of the wider streets, and a limited amount of fire fighting assisted in stopping fire spread at the perimeter. Fire breaks at Hiroshima were ineffective because the original fires were ignited on both sides of them, but at Nagasaki man-made fire breaks (9,000 and 11,000 feet southeast of

Ground Zero) combined with bucket-brigade activity stopped the spread of fire at two locations.

b. <u>Difficulties Encountered</u>. Within 5,000 feet of Ground Zero in all directions at Hiroshima, a large proportion of the serious casualties occurred. Thousands of persons were killed immediately by the explosion and additional thousands were injured, many critically. Approximately 70 per cent of the public fire department apparatus was immediately out of service (Photo 185), and over 80 per cent of the "on-duty" firemen were killed or incapacitated. Almost none of the "off-duty" firemen, who would normally be available, reported for duty. Thus, the public fire department had been dealt an instantaneous, paralyzing blow from which it could not recover. The streets were blocked by demolished buildings and their contents, debris covered a majority of the underground hydrants, and the general confusion was tremendous. Even if the fire department had remained intact, the general situation within 5,000 feet of Ground Zero would have been a hopeless one from the beginning. At a few places on the fire perimeter the public fire department performed some effective work but its efforts played a minor role in the over-all fire-fighting task. The most effective fire fighting was done by the civilian populace, aided by soldiers quartered in the area, who formed bucket brigades and passed buckets of water from tanks, open drainage ditches, and rivers. One 16-inch water main was broken by the collapse of the bridge which carried it; the booster pumping stations were damaged by blast; and large numbers of small feed lines were broken by the collapse of the buildings they served. An immediate reduction of water pressure in the system resulted. Later in the day the distribution system in the center of the city was shut off. The reservoir did not run dry and lack of water in the public water system apparently had no effect on the fire situation. It would have failed, no doubt, if a heavy demand had been placed on it. In Nagasaki, extensive and serious blast damage to buildings and casualties to persons were limited to within 7,000 feet of Ground Zero in the Urakami Valley. The Nakashima Valley was shielded from the blast by 900-foot hills, 6,000 feet southwest of Ground Zero. Consequently the public and volunteer fire departments escaped with only 35 per cent of their personnel killed or injured and 20-per-cent total damage to their pumping engines. These losses were light compared to those at Hiroshima. Except for minor casualties, the fire-fighting organization beyond 7,500 feet south and southeast of Ground Zero remained intact. The fire chief dispatched two pumping engines from the main fire station (9,500 feet southeast of Ground Zero) to combat the fires to the north, and dispatched men to establish liaison with the volunteer fire departments, as telephone communications had been disrupted. One truck penetrated to the vicinity of the gas works, 6,500 feet south of Ground Zero, arriving there about 10 minutes after the explosion, but it could go no farther because streets were obstructed by debris and buildings in the area to the north were in flames. This truck returned to the main fire station to assist in fighting fires in that vicinity. The public and volunteer fire departments fought against spread of fire within the area between 8,000 and 11,000 feet south of Ground Zero on the east side of Nagasaki Bay and in the area between 6,000 and 8,000 feet south of Ground Zero on the west side of the Urakami River, although seriously handicapped by decreasing water pressure in the city water system which finally became too low to be of use for fire-fighting purposes within 18 hours after the explosion. The blast caused five breaks in a 12-inch cast-iron main three feet below grade in a reclaimed area within 2,000 feet of Ground Zero by unevenly depressing the soil, and caused six additional major breaks, four of them by displacement of bridges which carried the pipes. Another contributing factor to the failure of the water supply was the breakage of several thousand service pipes resulting from collapse of buildings by blast or damage by fire. As in Hiroshima, bucket brigades utilizing water from tanks, wells, and water courses were most effective in limiting fire spread in fringe areas.

6. Extent and Cause of Fire Damage

a. Areas Involved. In Hiroshima a roughly circular area of 4.4 square miles was completely burned over. In Nagasaki an irregularly shaped area of 0.9 square mile was burned over on both banks of the Urakami River and on the north bank of the Nakashima River. There were few combustible buildings and fire-resistive buildings with combustible contents remaining unburned within the burned-over areas in both cities. (Photos 176-187) The most distant extremities of the burned-over areas were 10,200 feet to the north and east from Ground Zero in Hiroshima, and 11,200 feet to the south from Ground Zero in Nagasaki. The shape and position of the fire pattern in each city were the result of the location of the bomb burst and the characteristics of the terrain and built-up areas.

b. Radiant Heat Ignition. The ability of radiant heat from the atomic bombs to ignite combustible materials was of much interest. In both cities fire-resistive buildings with combustible contents were selected for study because these buildings suffered less structural damage and had fewer casualties, so that better visual and oral evidence could be obtained. In Hiroshima, it was established that radiant heat from the bomb was the probable cause of initial ignition in 20 per cent of the fire-resistive buildings, all of which were within 6,500 feet of Ground Zero. Comparable figures were not available for Nagasaki. It has been estimated, however, that in Nagasaki 90 per cent of all initial fires in fire-resistive buildings within 4,000 feet of Ground Zero might be attributed to radiant heat; in comparison, only about 30 per cent of such fires in similar buildings in Hiroshima within 4,000 feet of Ground Zero were caused by radiant heat. Although the Nagasaki bomb was reported to have been more efficient than the Hiroshima bomb, there is considerable doubt about the 3-to-1 advantage indicated for its effectiveness as a source of direct ignition.

c. Fire Spread. Despite the fact that radiant heat started more fires in fire-resistive buildings in Nagasaki than in Hiroshima, a higher percentage of the buildings in Hiroshima was affected by fire and sustained more extensive fire damage, evidently as a result of fire spread. In Hiroshima a large proportion of the fire-resistive buildings comprised offices, banks, stores, and warehouses which were located in congested, combustible areas, whereas similar structures in Nagasaki were principally school, college, and institution buildings, most of which were in groups or set off by themselves and not closely exposed to congested, combustible areas. In Nagasaki all of the 31 fire-resistive buildings which sustained fire damage were within or adjacent to the burned-over area and within 4,000 feet of Ground Zero, whereas in Hiroshima only 69 per cent, or 40 buildings, were within 4,000 feet of Ground Zero. In order to demonstrate that there was more fire spread to fire-resistive buildings in Hiroshima than in Nagasaki, the following comparison is presented: TABLE 39

Fire-Resistive Buildings	Nagasaki	Hiroshima
No. of buildings within or adjacent to burned-over area and within 4,000 ft of GZ	37	41
No. of buildings involved by fire within 4,000 ft of GZ	31	40
Percentage of buildings involved by fire within 4,000 ft of GZ	82	98
Percentage of total floor area burned within 4000 feet	52	89
Percentage of buildings involved in fire within or adjacent to entirely burned-over area (max dist 6,500 ft from GZ)	--	91
Percentage of total floor area burned within 6,500 ft from GZ	--	72

d. Effect of Exposure Distance on Fire Spread. In Hiroshima, a special study of exposure distances at 107 burned and 23 unburned fire-resistive, noncombustible, and combustible buildings, and 8 burned and 7 unburned combustible bridges within or adjacent to the burned-over area led to the conclusion that there was a relationship between incidence of fire in the buildings and bridges and their distances from burned exposing buildings. Fire definitely failed to spread by exposure to only one fire-resistive and one noncombustible building among the 107 buildings which were burned. The study is summarized as follows:

TABLE #40

Combustibility Classification	Average distance (ft) from nearest exposing bldg from which fire spread may have occurred	No. of Cases	Average distance (ft) from nearest exposing building from which fire spread did not occur	No. of Cases
Fire-resistive bldgs	20	57	90	7
Noncombustible bldgs	5	7	30	5
Combustible bldgs	20	41	40	13
Average for all bldgs	20	105	50	25
Combustible bridges	35	8	70	7

(A similar study was not conducted in Nagasaki)

At Hiroshima studies were also made which established a relationship between probability of fire spread and built-up density, and between probability of fire spread and exposure distances for the conflagration. The results indicated that there was a rapid increase in probability of fire spread as built-up density increased above 12 per cent and as exposure distances decreased below 50 feet; and that there was a comparatively small return in immunity from fire spread among combustible buildings averaging one and a half stories with a decrease in built-up density below 12 per cent and an increase in exposure distance above 50 feet.

e. Contributive Effects of Blast to Fire Damage. Within the areas finally burned over in both cities, the bomb blast rendered most buildings of all fire classifications extremely vulnerable to spread of fire by exposure by breaking all glass and blowing in or damaging fire shutters, stripping wall and roof sheathing, and collapsing walls and roofs. Likewise, it left practically all buildings in a condition extremely favorable to internal fire spread by blowing off or damaging doors at stairs, elevators, and fire walls, blowing down partitions, and rupturing and collapsing floors. In fire-resistive buildings, with almost no exceptions, fires spread upward, and in about two-thirds of the cases also spread downward, as indicated by burned basements in Hiroshima.

f. Comparison of Fire and Blast Damage

(1) Fire-Resistive Buildings. Except in three buildings in Hiroshima, all structural damage to fire-resistive buildings in both cities was caused by blast. On the other hand, fire damage to the interiors and contents of fire-resistive buildings greatly exceeded damage by blast and debris (Photos 177-189). Most of these buildings had combustible interior construction as well as a considerable amount of combustible contents, and combustion in the parts of the buildings which burned out was practically complete. Structural damage to the three fire-resistive buildings in Hiroshima was the result of intense heat of long duration which was dependent

upon the nature of the contents (grain in two cases, and books in the other) and confinement of the heat (Photos 190-191).

(2) Noncombustible Buildings. In both cities noncombustible buildings, most of which had steel frames sheathed with corrugated iron or corrugated asbestos, were structurally damaged principally by blast. In Hiroshima, where most of these buildings were small and all had light, steel frames, a major part of serious damage to contents was caused by fire. In Nagasaki the noncombustible buildings were comparatively large and were approximately equally divided among heavy and light, steel-frame construction. Fire caused no serious damage to contents in the heavy, steel-frame buildings and a very small amount of serious damage in the light, steel-frame buildings (Photos 192-193). About 50 per cent of the noncombustible buildings in Hiroshima had combustible contents whereas most of those in Nagasaki had noncombustible contents.

(3) Combustible Buildings. Combustible buildings in both cities were structurally damaged principally by blast, but it is believed that fire caused the majority of severe damage to contents. After sustaining damage of varying degrees by blast, approximately 50,000 of 90,000 combustible buildings in Hiroshima and approximately 13,000 of 55,000 combustible buildings in

Photo 185. Hiroshima. One of the reasons why the fire department was unable to function.

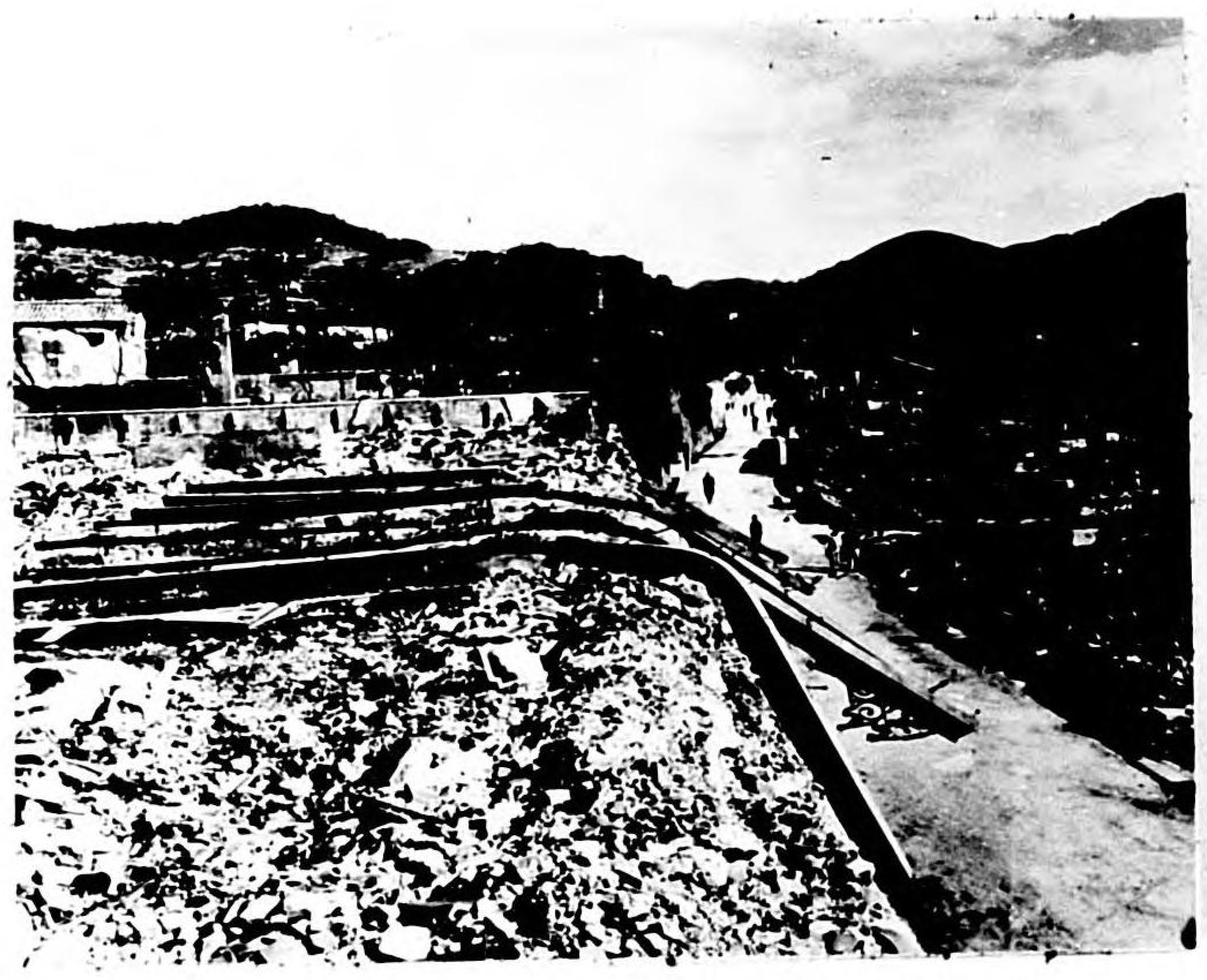

Photo 186. Nagasaki. Area 10,000 feet from GZ. Fire damage. Buckled I-beams.

Photo 187. Nagasaki. Same as Photo 186.

Photo 188. Hiroshima City Hall, 3,300 feet from GZ. West elevation of reinforced-concrete building--minor damage only: sash blown out, trim and finish consumed by fire. Few tile partitions blown out.

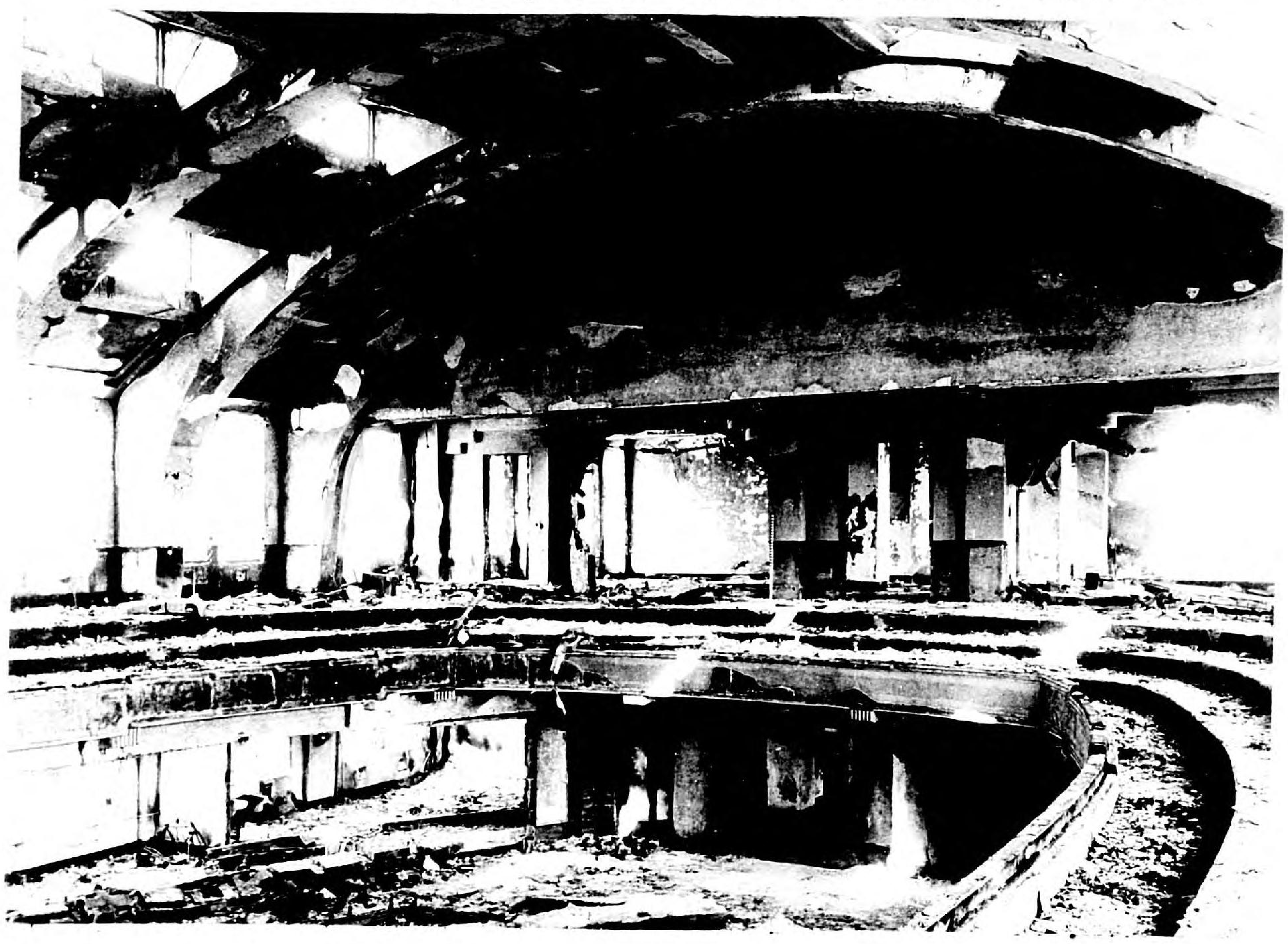

Photo 189. Interior of Photo 188, showing spalling of plaster and total damage to contents by fire, but little damage to framing and walls.

Photo 190. Hiroshima. Misasa Credit Association warehouse, reinforced-concrete building 5,800 feet from GZ. Second story of east section showing structural fire damage to roof, cracks in walls spalling of concrete on columns, and deep ashes on floor.

Photo 191. Same as Photo 190. View of first story showing structural damage to second floor by fire: spalling and disintegration of concrete.

Photo 192. Nagasaki. Steel-frame building 6,400 feet from GZ which suffered heavy superficial and slight structural damage from blast. Combustible debris burned.

Photo 193. Nagasaki. Steel-frame building 6,300 feet from GZ. Damage by blast and fire. Effect of intense heat on steel trusses.

Photo 194. Nagasaki. Load-bearing brick-wall structure, 6,400 feet from GZ. Roof and contents destroyed by fire.

(Photo 194)

Nagasaki were totally damaged by fire.

(4) Bridges. In Hiroshima eight of 15 combustible bridges within or adjacent to the burned-over area were heavily or totally damaged by fire, three after having been damaged initially by blast. Each of the eight bridges was ignited by spread of fire from near-by combustible buildings. In Nagasaki one combustible bridge was totally damaged by fire after sustaining blast damage. This bridge probably was ignited by flaming debris from burning buildings. Combustible bridges located outside the burned-over areas sustained no fire damage, and concrete and steel bridges, wherever located, were not damaged by fire alone in either city.

K. Comments. (all caps)

1. Hiroshima was an excellent test target for the atomic bomb from a fire standpoint principally because the shape of the densely and and moderately built-up areas was roughly circular over broad, flat terrain which was cut up by an extensive network of rivers and man-made fire breaks. The maximum return in fire damage was obtained in Hiroshima because the bomb detonated over the heart of the city.

2. Nagasaki. Although the shapes of the built-up areas of Nagasaki were very irregular, lying on the narrow shores of, and in the valleys extending out from, Nagasaki Bay, it was an excellent test target for the atomic bomb from a fire standpoint because its urban areas

were extremely congested and combustible, and the bay and the Urakami River were extensive fire breaks. The maximum return in fire damage was not obtained, however, because the bomb detonated too far to the north. It is believed that the burned-over area in Nagasaki would have been doubled, and possibly tripled, if the bomb had been detonated at approximately the same altitude but 6,500 feet directly south of Ground Zero, where a large proportion of the central and eastern parts of the city in the Nakashima Valley, and the north, southeast and southwest parts of the city as well, would have been directly exposed to the blast and heat effects of the bomb.

3. Effect of Terrain. The shape of the burned area in Hiroshima leads to the conclusion that the detonation of an atomic bomb over the center of any flat, uniformly built-up, combustible city would result in a roughly circular area of fire damage, provided there was no more than a light, natural ground wind. The shape of the burned area in Nagasaki illustrates the effect of shielding in limiting the extent of fire damage, at least in the presence of a light, natural ground wind.

CHAPTER VII

STRUCTURAL CONSIDERATIONS

1. Early Conclusions Sustained. The Japanese survey afforded an opportunity to re-examine the structural conclusions stated in the European report of the Division (PDD 68). The second survey disclosed no reasons for changing the following conclusions of the first:

a. Blast Loading. When a bomb detonates inside a building, the slab, beams, and columns above the point of detonation are subjected to loads in the opposite direction from those for which they were designed. Where the principal framing members were of steel this reversed loading was of small consequence. Reinforced-concrete members, on the contrary, were unable to resist such reversals. In particular, columns failed by pulling apart at regions where reinforcing rods were lapped, and beams failed along the planes where main rods were bent to furnish resistance to diagonal tension. The use of a small amount of negative reinforcement throughout the length of a beam and the use of vertical stirrups instead of bent rods for "shear" reinforcement would greatly strengthen a beam against reversed loads.

(1) Trusses, or, in general, open-web members, were less damaged by direct hits and blast than were girders (i.e., solid-web members).

(2) Continuity and bracing were of considerable value in limiting the extent of spreading collapse.

(3) Wall-bearing structures and the so-called slow-burning mill-type with ~~poor~~ weak connections between

beams and columns were the poorest types from the standpoint of bomb resistance.

(4) <u>In multi-story construction</u> the damage to steel structures was less widespread than in those of reinforced concrete; the former would also be far easier to repair.

(5) <u>Field-riveted structures</u> appeared to have no advantage over those that were field bolted. Data are still lacking on the action of welded structures.

(6) <u>Asbestos Sheathing</u>. Buildings roofed and sheathed with corrugated asbestos suffered little distortion or damage to the structural frame even when relatively close to the point of detonation of a high-explosive bomb (or, as may now be added, an atomic bomb), since the asbestos shattered so quickly that little force was exerted on the frame. Fire caused little further damage because there was nothing to confine the heat.

b. <u>Concrete Structures</u>. Although the earlier conclusions regarding the effects of high-explosive bombs on reinforced-concrete structures were confirmed, it should be made clear that relatively little additional information was obtained on these effects for the following reasons:

(1) The Japanese had no structures of the heavy bunker (shelter) and submarine-pen types.

(2) High-explosive bombs were dropped, in general, only on industrial plants and these had comparatively few reinforced-concrete buildings.

(3) The reinforced-concrete buildings of Japan were largely multi-story structures which were concentrated in cities, and Japanese cities were attacked only with incendiary bombs.

On the contrary, a vast amount of information was collected on the effect of the atomic bombs on reinforced-concrete structures. Detailed examples of such damage are given in profusion in the Division's reports on Hiroshima and Nagasaki, (PPD 69 and 70)

c. Steel Structures. The great majority of high-explosive-bomb incidents reported on in Japan dealt with steel structures, most of which compared favorably with typical American structures in the strength of both their main members and connections. Hence, the MAE figures which are presented in another chapter of this report may be considered applicable to structures in the United States.

2. New Considerations (Anti-Atomic-Bomb Construction). Probably no structure could withstand the near detonation of an atomic bomb. Such a conclusion, however, should not obscure the fact that precautionary measures can measurably decrease the effects on structures which are moderately removed from the bomb. It will be understood that conclusions reached in this report are based on the

observed effects of two particular bombs. Differences which might result from different types of atomic bombs, when and if such are developed, have not been considered.

a. Military. A structure designed to be bomb proof against a 2,000- or 4,000-pound, high-explosive bomb would probably be resistant to any except a very near miss of an atomic bomb.

(1) There is an imperative need for an experimental underground detonation of an atomic bomb. Such a test may disclose that at moderate distances a structure on the surface is superior to a subsurface structure.

(2) Important structures should be dispersed to reduce the attractiveness of a target.

(3) Vital posts should be built (suitably separated), equipped, and manned in duplicate.

b. Urban. Studies in progress, to be reported on by medical groups, will tell how much cover of reinforced concrete or other material is needed to protect against the radiation effects of the atomic bomb. Assuming adequate warning of an attack, this information will enable a shelter policy to be evolved. Admittedly, if entire city populations are to be protected, the extent and cost of such a policy stagger the imagination.

(1) Curtain walls in skeleton construction constitute a great hazard. A poured-and-attached wall will increase the blast loads on a building frame but

is to be preferred to a wall of relatively loose units.

(2) In time of danger, load-bearing brick-wall buildings and combustible construction must be especially shunned. Perhaps the time has come to search for and require for future construction a type of common residence which will possess bomb-resistant qualities that far exceed those of the present prevalent types.

(3) Japanese residences, predominantly of wooden construction, fared as follows under the atomic bomb, distances being radii from Ground Zero:

Complete collapse	2,500 feet
Damaged beyond repair.	5,200 feet
Uninhabitable without extensive repair	7,500 feet
Uninhabitable without first-aid repair	8,000 feet

From knowledge of the effects of the German blitz on their cities, British experts have concluded that the above distances would also apply to British residences in an atomic-bomb attack. There is no reason to suppose that American homes would fare any better.

c. Industrial. The superior type of structure is one with a sturdy frame of steel or reinforced concrete, covered with friable siding and roofing.

(1) Close-at-hand shelters (similar, perhaps, to the industrial and urban bunkers which were built by the Germans (PDD 22)) must be provided for workers.

(2) A supply of covers (i.e., tarpaulins) must be provided to give equipment immediate protection against weather.

(3) Different plants must be separated by enough distance to insure that several plants could not be involved in a single bomb incident.

3. Comparison of High-Explosive Bomb Sizes. This Division caused to be written in the Survey's "Over-All Report (European War)" the statement: "As yet no final answer may be given on the relative merits of the small and large bomb when dropped on the usual industrial target." It is probable that this statement would be altered by every observer who visited both theaters; indeed, by those who visited Japan only. In the Japanese theater the 4,000-pound bomb (unused in Europe) was measurably superior as a blast weapon to any other, pound for pound. Photos 195 and 196 show the difference between the gnawing action of four 500-pound bombs and the blast action of a 4,000-pound bomb. In general, there was a steady gain in efficiency in going from the light bombs up to the 4,000-pound size. Any tendency to conclude that this gain would continue indefinitely

Photo 195. Gnawing action of four 500-pound bombs.

Photo 196. Blast action of a 4,000-pound bomb.

was stopped by the fact that the single heavier bomb for which data were obtained, that is, the 10,000-pound bomb, was again clearly inferior (pound for pound) to the 4,000-pound bomb.

4. Outstanding Structural Incidents. A number of impressive pictures of structural action were observed which merit brief mention.

a. An L-shaped, three-story, reinforced-concrete school at Nagasaki received the full blast of the atomic bomb on the outer face of one leg. The pressure was sufficient to cause the heavy columns, each approximately one foot by six feet, on the inner face of the other leg to fail in shear in the ground story (Photo 197).

b. A reinforced-concrete T-beam bridge at Hiroshima lost a bent in the flood which followed the hurricane. The adjacent bent was also severely damaged, but one-half of the roadway remained in position and continued to carry unrestricted traffic (Photo 198). Nothing was learned, unfortunately, about the details of the reinforcing.

c. A number of reinforced-concrete stacks were seen which continued to stand after losing a large part of their cross section. Perhaps the most impressive example was a stack at the Mitsubishi Aircraft Plant (Target 90:20-193) at Nagoya, which is shown in Photos 199-203 herewith.

d. Structures were encountered which possessed amazing stiffness after portions of their supports were severed or removed. Large sections of steel buildings stood without apparent distortion after columns were cut (Photo 204); others after footings were

7

Photo 197. L-shaped, three-story, reinforced-concrete school received full blast of atomic bomb on outer face of one leg. Pressure caused heavy columns, each approximately 1 by 6 feet, on inner face of other leg to fail in shear in the ground story.

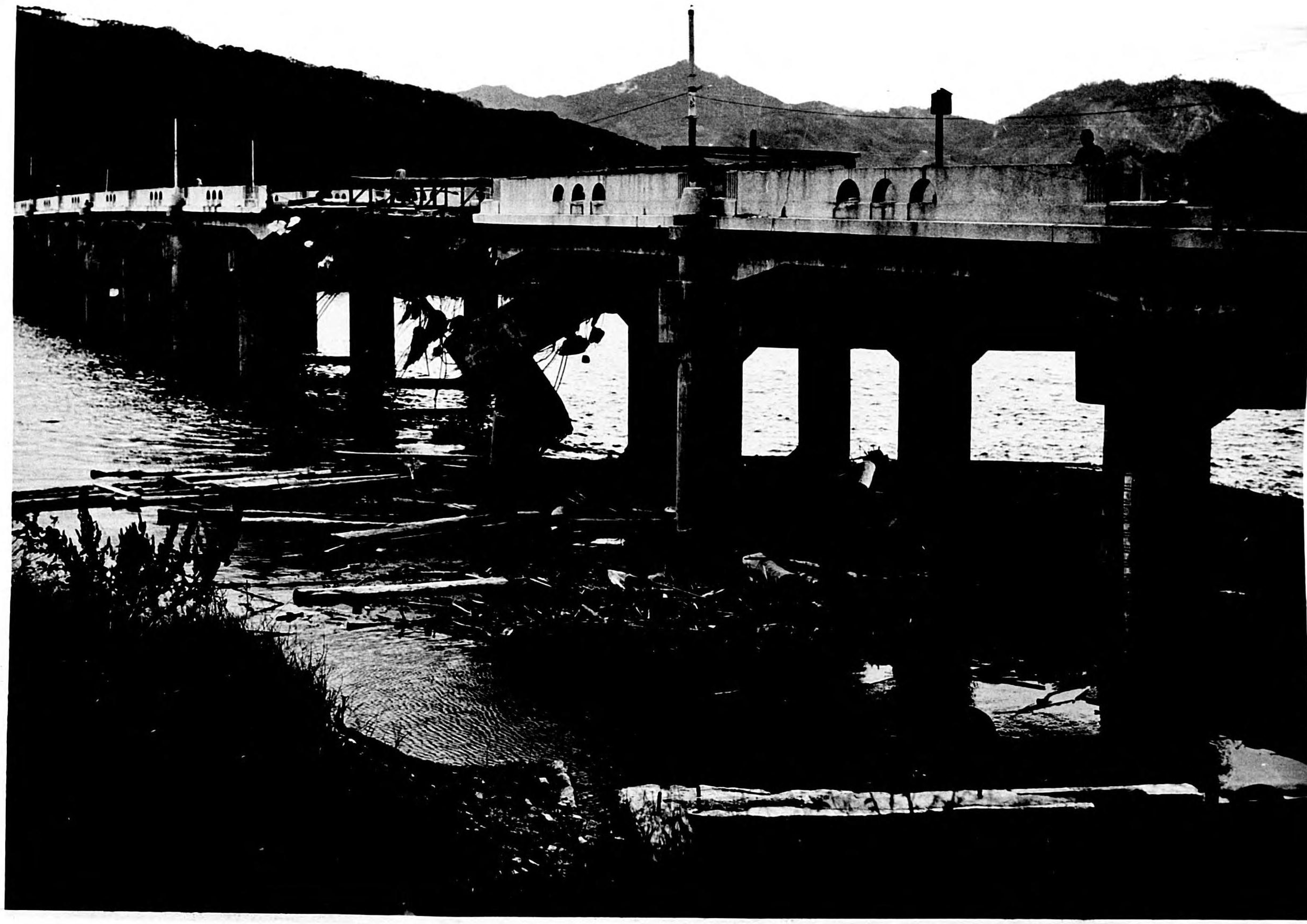

Photo 198. Reinforced-concrete bridge lost bent in flood. Adjacent bent was also severely damaged, but one-half of roadway remained in position and continued to carry unrestricted traffic.

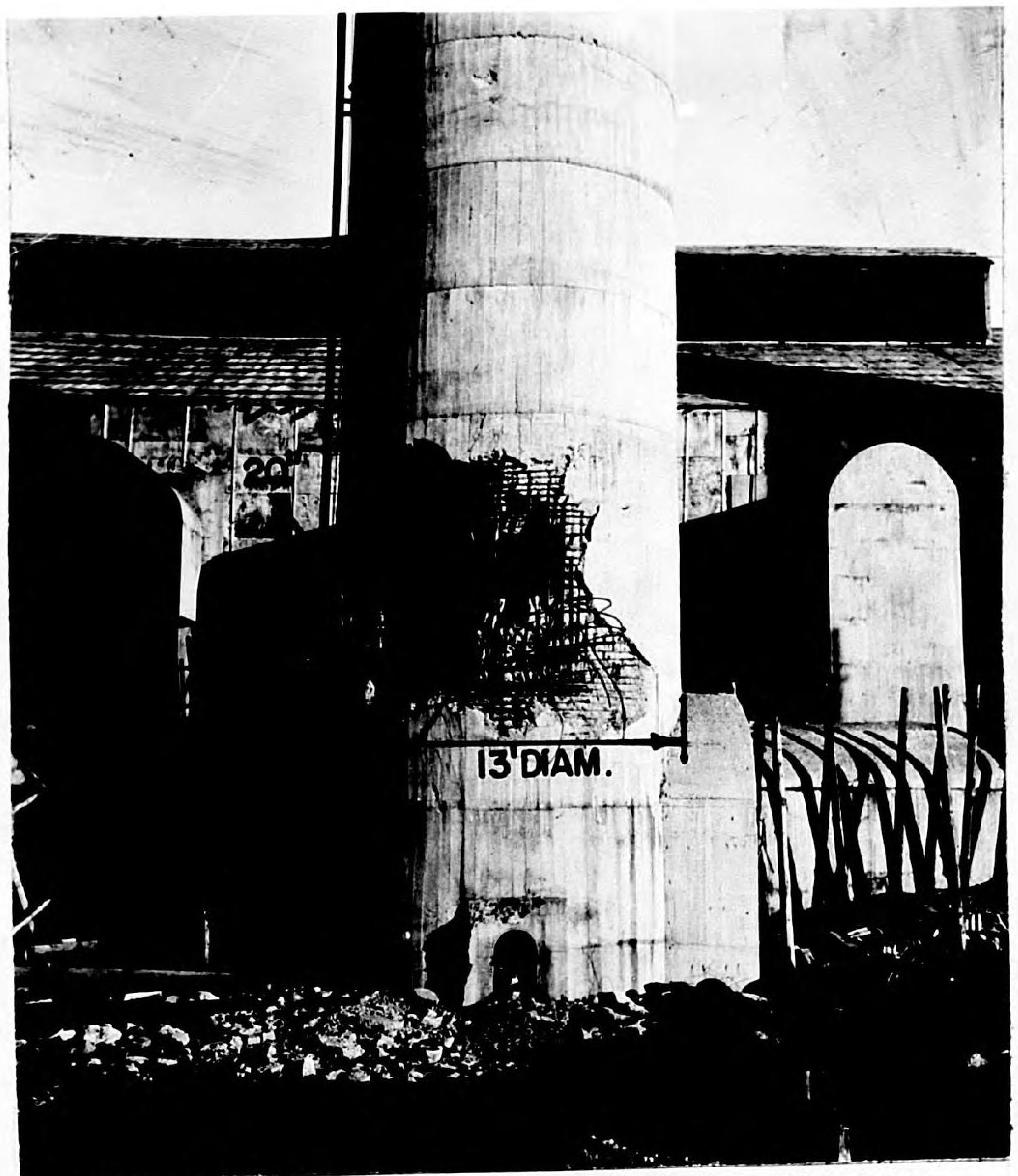

Photo 199. Perforations at base of stack looking east.

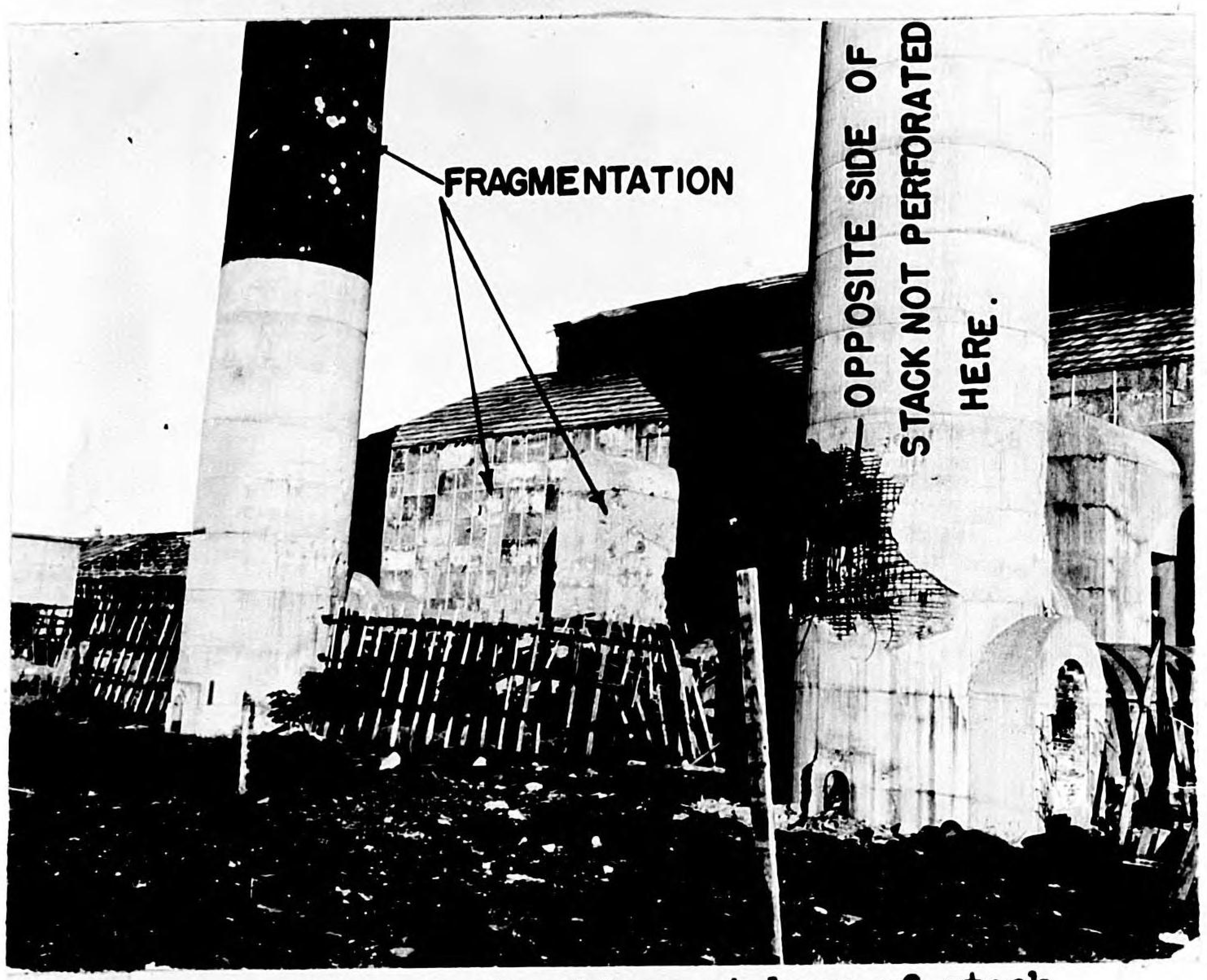

Photo 200. Perforations at base of stack looking northeast.

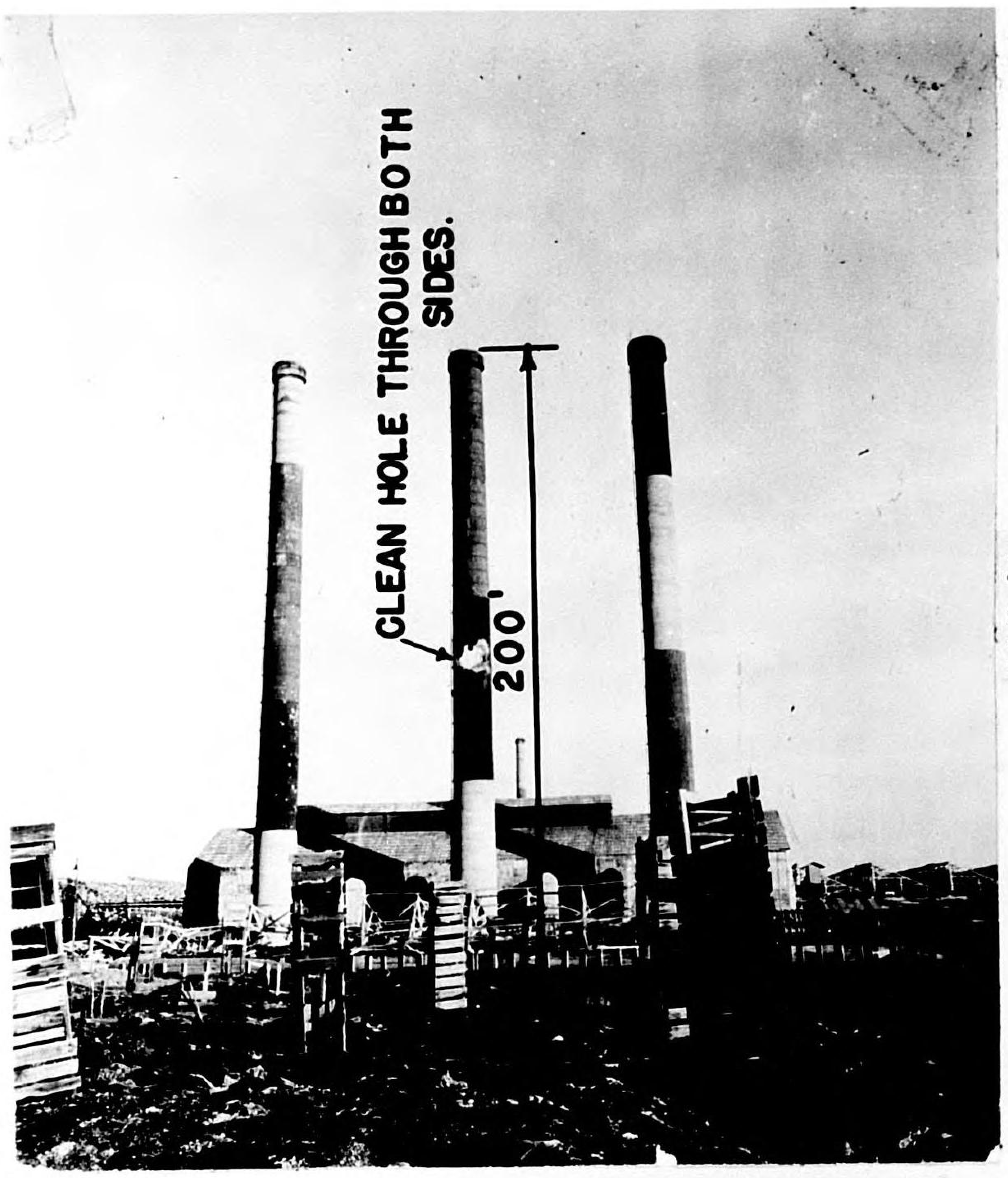

Photo 201. Upper perforation of reinforced-concrete stacks looking east.

Photo 202. Upper perforations stacks looking northeast.

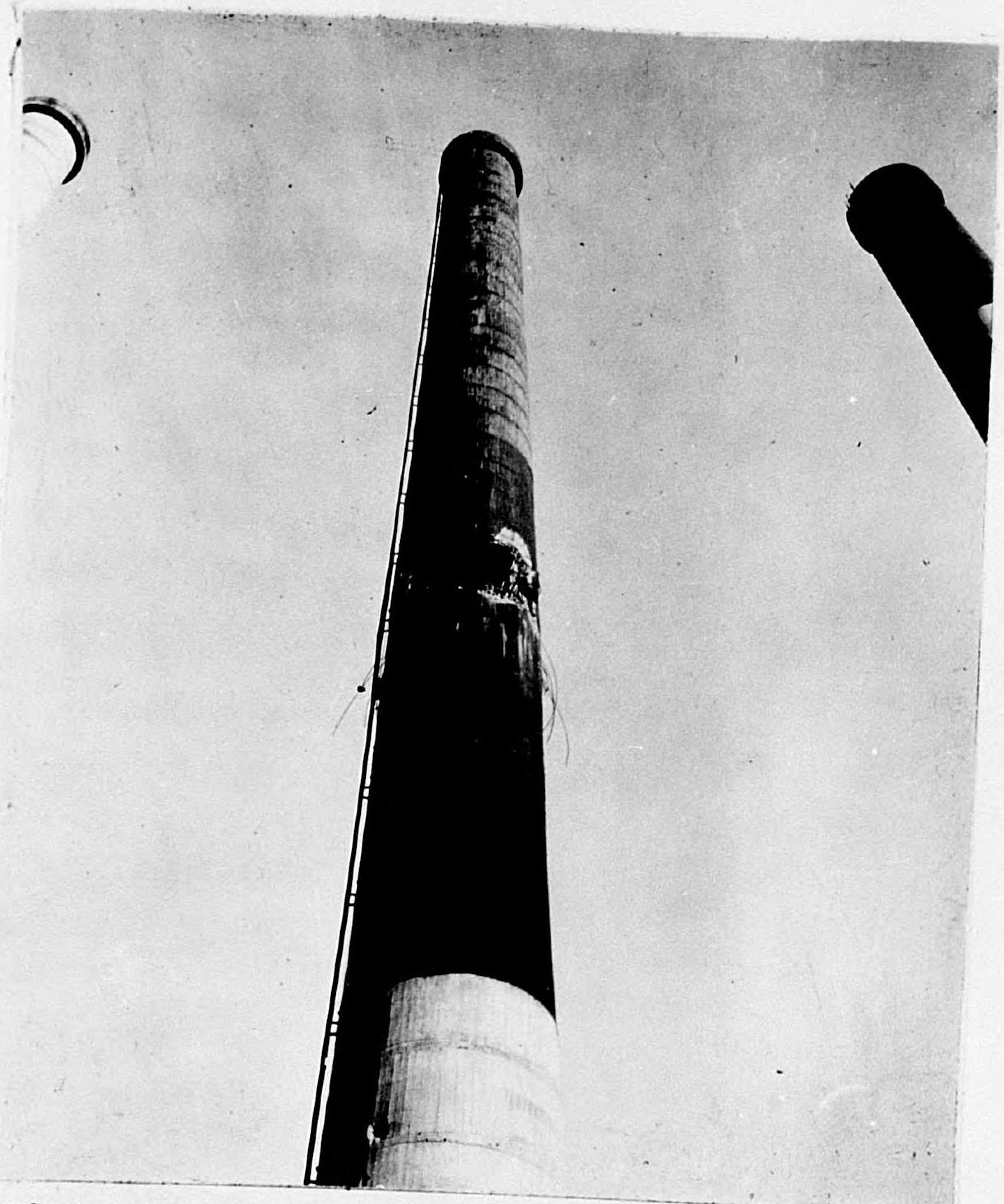

Photo 203. Close view of perforations looking northeast.

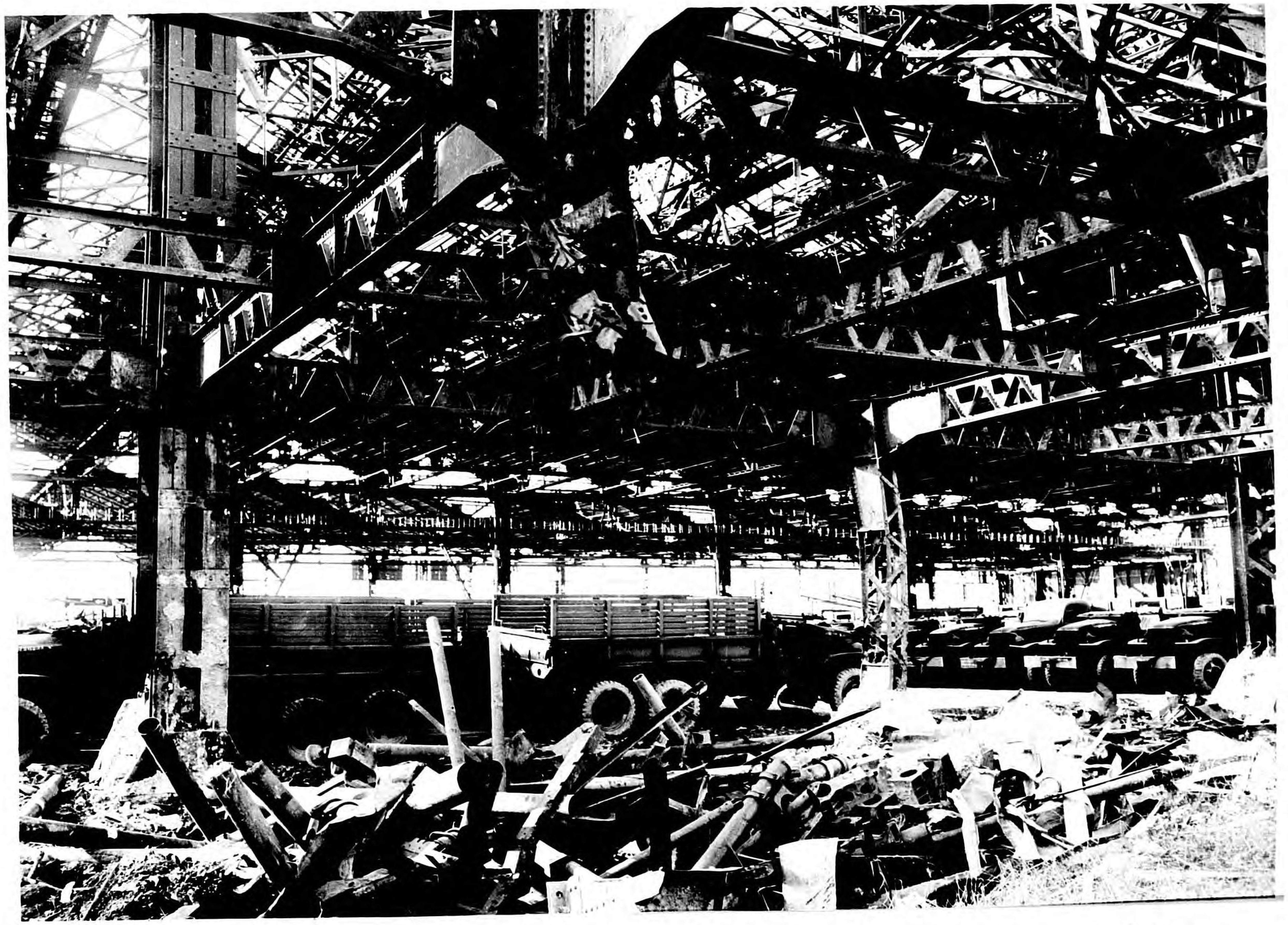

Photo 204. Large sections of this steel building stood without apparent distortion after columns were cut.

blown from under columns. Likewise, portions of reinforced-concrete structures remained in positions after great holes had been blown in their lower sections. Photo 205 illustrates an example where the interior columns of a three-bay-wide building were severed, as were also a corner column and the sections between windows, but the third-floor ~~and~~ roof sections cantilevered out from the undamaged part. Photo 206 shows another example at the other end of the same building.

e. Buildings somehow hung together when portions were undermined by bombs. Photo 207 illustrates a bay and a stairwell which were lowered by cratering bombs.

Photo 205. Interior columns of three-bay-wide building severed, also a corner column and sections between windows, but third-floor-and-roof sections cantilevered out from undamaged part.

Photo 206. Another example at other end of building shown in Photo 205.

Photo 207. Bay and stairwell lowered by cratering bombs.