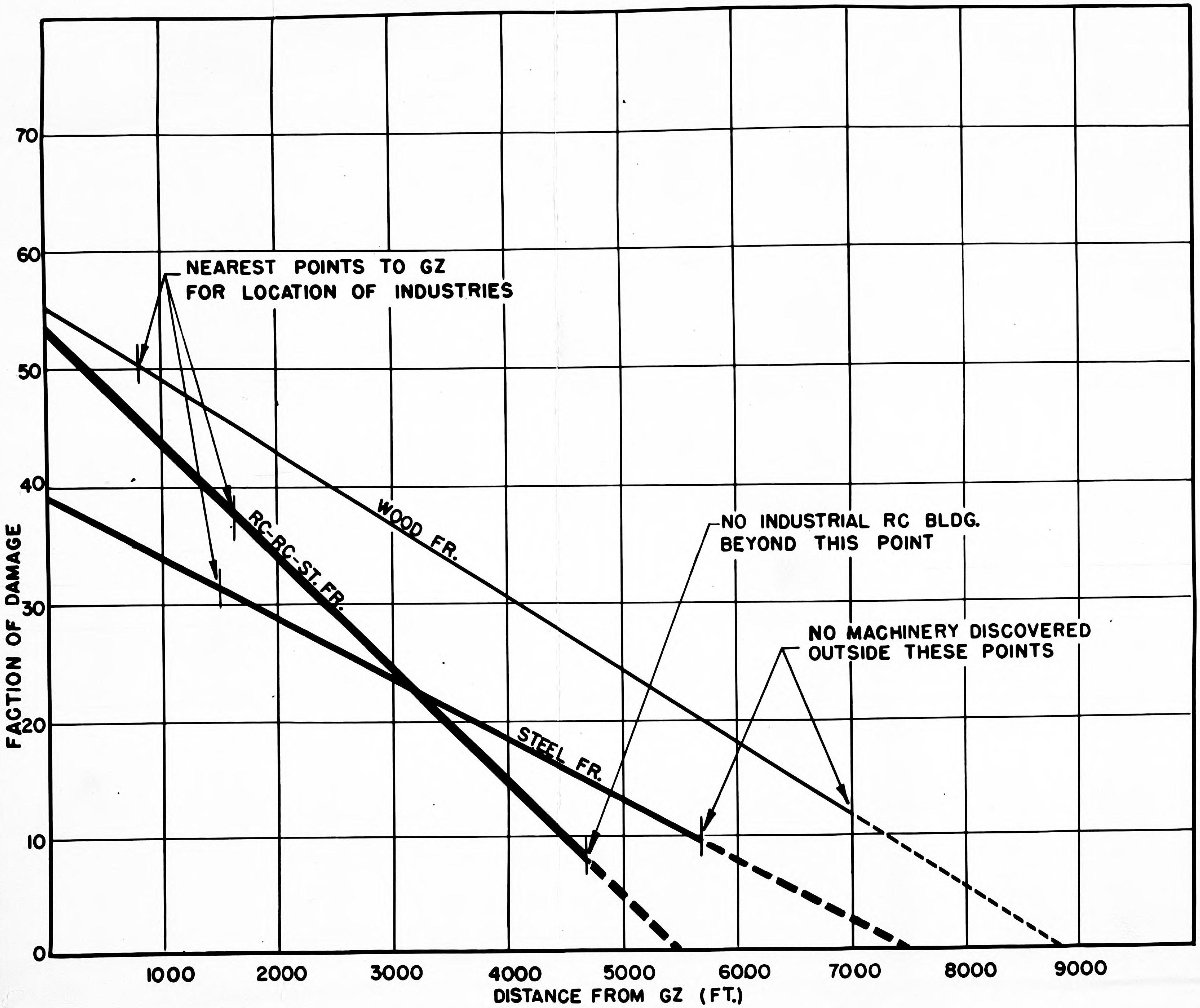
DAMAGE TO MACHINE TOOLS BY ATOMIC BOMB

NAGASAKI (GRAPHS FOR TOTAL AND HEAVY DAMAGE)



MAE ——— 1.68 SQ. MI.
MAE STR. 9.90 SQ. MI.

MAE ▬▬ .872 SQ. MI.
MAE STR. 3.30 SQ. MI.

MAE ███ .553 SQ. MI.
MAE STR. .52 SQ. MI.

FIGURE 4-30

CHAPTER V

DAMAGE TO UTILITIES

A. SUMMARY

1. Scope. In the study of industrial targets in Japan by Physical Damage teams, the main utility information gathered was that concerning electric, water, gas and sewerage systems.

2. Vulnerability of Utilities. Utilities as a whole were found to be vulnerable to air attacks. They sustained considerable damage which in many cases retarded plants' production capacities although the processing machinery was intact.

3. Effective Types of Bombs. High-explosive, incendiary, and atomic bombs were used with good results in attacks on Japanese industries. Although sufficient data were not available to permit calculations of Mean Areas of Effectiveness (MAE) for high-explosive and incendiary bombs, certain conclusions have been reached.

4. Causes of Damage. High-explosive bombs damaged utility installations by blast, fragmentation, earthshock, debris and, occasionally, by fire. Blast generally damaged aerial wiring, switchboards, transformers, and the like. Although such damage was in most cases comparatively easy to repair, it would, when extended over a large part of the system, cause much disruption of industrial production.

5. Fragmentation. Fragmentation was an effective agent for damage to cables, transformers, switchboards, tanks and similar installations. The effective radius for fragmentation damage was approximately

three times the radius of the bomb crater.

6. Earthshock. Earthshock was effective in damaging underground installations such as gas and water mains, and cables. The maximum radius for earthshock severe enough to do damage was approximately three times the radius of the bomb crater.

7. Debris. Debris in the form of collapsing structural members of industrial buildings did much damage. The degree of this type of damage is closely related to the building type, and it is not possible to predict exactly how much damage may be expected from this source. Generally speaking, however, the utility damage caused by debris roughly amounted to 50 per cent of the structural building damage.

8. Fire. Fire caused by hot fragments from high-explosive bombs did occasionally ignite transformers and switchboards, but, on the whole, not much weight can be given to this damage agent.

9. Incendiaries. Incendiary bombs were indirectly responsible for damage, although it was small compared with high-explosive damage. Electrical installations were often consumed in burning buildings. The amount of damage to be expected from incendiary bombs is therefore closely connected with the degree of combustibility of the buildings concerned.

10. Atomic Bombs. The effect of the atomic bombs on utilities in Hiroshima and Nagasaki was great. The major effect of the atomic bombs on utilities was caused by blast and debris which were effective over a large area. Fire, though effective, was less important. Table 36 summarizes the damage to utilities in Nagasaki and Hiroshima.

B. GENERAL INFORMATION

1. Vulnerability of Utilities. Utilities in Japan, although generally inferior to American systems, adequately served their purposes. Electric and gas plant installations were comparable with American standards, but water and sewer systems were inferior. Underground conduits were rarely used and therefore utility installations were vulnerable to aerial attacks and, in particular, to the effects of the atomic bomb.

2. Condition at End of Hostilities. At the end of the war utilities were in a bad condition because of severe damage caused by aerial attacks. Most industrial utilities were unable to operate adequately, and it would have taken much time to bring them back to their full capacity.

C. DAMAGE ANALYSIS

1. High-explosive Bombs. High-explosive bombs caused damage by blast, earthshock, fragmentation, debris, and fire.

a. Blast. Blast damaged switchboards, transformers and aerial wiring. This damage was generally not serious and could often be repaired within a short time by maintenance crews. Several examples were studied where gas tanks had been collapsed by the blast from 1,000-pound, high-explosive bombs detonating 150 feet away.

b. Earth Shock. Cratering bombs produced shock waves of sufficient magnitude to damage effectively underground installations, such as water and gas mains, within a distance of three to four times the

TABLE 36

DAMAGE TO PLANT UTILITIES BY THE ATOMIC BOMB

HIROSHIMA - NAGASAKI

SYSTEM	MAX DIST (FT) FROM GZ THAT DAMAGE WAS FOUND			CAUSE OF DAMAGE	OVER-ALL DAMAGE PERCENTAGE			MAN HOURS * ESTIMATED REPAIR TIME	COMPONENTS DAMAGED
	Wood-frame Bldgs	Steel-frame Bldgs	Reinforced-concrete Bldgs	Blast, Fire, Debris	Wood	Steel	RC		
Electric	10,000	5,000	7,000	"	100	40	60	800,000	Transformers, switchboards, cables and overhead electric poles
Gas	7,000	5,000	7,000	"	100	40	40	400,000	Tanks, producers, main and distribution pipe
Water	10,000	5,000	7,000	"	100	30	20	100,000	Water mains and distribution pipes
Communications	10,000	5,000	7,000	"	100	50	60	150,000	Cables and wire
Transportation	10,000	5,000	7,000	"	75	10	10	50,000	Truck and rolling stock

* Japanese estimate

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radius of the bomb crater. Much damage was also sustained by water and gas escaping from ruptured mains. Of the bombs studied in Japan, 500-pound bombs, on a tonnage basis, appeared to be most suitable for damaging underground installations. Damage from earthshock was generally heavy and required a great deal of time and labor to repair.

c. Fragmentation. Fragments damaged the prominent and heavier items of utility equipment, such as switch gear, switch panels, control boxes, telephone switchboards, control centers, pumps, tanks, large overhead steam and gas lines. Elevated water tanks and gas holders were also severely damaged by large fragments; however, these tanks or pipes were easily patched by welding, and did not constitute as serious an item of damage as that of fittings, pieces of rotating machinery, and transformers.

d. Debris. Debris caused severe damage within buildings. This damage depended to a large extent on the degree of structural damage

No break

and upon the nature of the debris. It is estimated that damage by debris to utilities in a building amounted to 50 per cent of the structural building damage. Debris damage was often severe enough to curtail production in industrial plants even though the machinery was only slightly damaged.

e. Fire. Fire caused by the flame front or from hot fragments was observed, but such cases were rare. Transformers were most vulnerable to this damage agent. The thin-walled casing of the transformer contained a special type of cooling oil which was easily ignited when hot fragments pierced the casing. In such cases the transformers were totally damaged.

2. Incendiary Bombs

a. Incendiary versus High Explosive. Incendiary bombs were widely used on Japanese cities, but their effect on utility installations was less than that of high-explosive bombs.

b. Indirect Effect. In only a few instances was it observed that utility installations had been damaged by fire as a result of direct contact with incendiary bombs. Much fire damage, however, was caused by indirect fires, i.e. fires produced in buildings by the bombs. It is therefore clear that the ability of incendiary bombs to damage utility installations in buildings depended to a large extent on the combustibility of the building.

3. Atomic Bombs

a. Effective Damage Agent. The atomic bombs which detonated above Hiroshima and Nagasaki were extremely effective in damaging utility installations. The limit for this damage was approximately 10,000 feet from Ground Zero (GZ), i.e., the point on the ground vertically below the bomb's point of detonation.

b. Causes of Damage. In contrast to the effects of high-explosive bombs which were in most cases direct, the damage caused by the atomic bombs was mostly indirect (fire and debris), although considerable damage was also caused directly by blast.

c. Degree of Damage. The degree of damage inflicted on utilities was generally not severe, but it was extensive.

(1) Installations Affected. Damage to utility installations is shown in Photos 120 - 143. Switchboards, tanks, cables, steel towers, and electric poles were damaged by blast up to 10,000 feet from GZ. Water, gas and air pipes, cables and switchboxes fixed to steel frames were distorted because of displacement of the collapsing steel structures.

(2) Value of Underground Conduits. Less damage would have been sustained if the utility installations had been carried in underground conduits which is the practice in most United States industrial plants. The damage to underground utilities in both cities was almost negligible.

d. Blast Walls. Reinforced-concrete blast walls, either poured *in situ* or pre-cast, were used extensively in Nagasaki. They proved to be very effective and saved much equipment from damage by blast and debris.

e. <u>Primary Fire Damage</u>. There was no evidence of primary fire damage to utilities but fires did occur, although infrequently, in steel-frame buildings. The extent of fire damage depended entirely on the buildings' combustibility.

f. <u>Damage to Utilities in Reinforced-Concrete Buildings</u>.

(1) <u>Fire</u>. Damage to utilities in reinforced-concrete buildings was caused largely by secondary fires. The amount of damage in these buildings was severe. However, it must be pointed out that most of the reinforced-concrete buildings had been built originally for school purposes, and therefore had a large amount of interior wooden trimmings. ~~Typical damage in these buildings is shown in Photos [illegible].~~ ?

(2) <u>Debris</u>. Damage to utilities in reinforced-concrete buildings was also caused by debris when part of the structures collapsed. The extent of this damage depended solely on the strength of the structure . ~~([illegible]).~~

(3) <u>Effect of Design</u>. If the reinforced-concrete structures had been designed for industrial purposes the amount of damage sustained would have been considerably less.

g. <u>Damage to Utilities in Wood-frame Structures</u>. Utilities in wood-frame structures were most vulnerable to the atomic bombs and sustained total damage in all plants surveyed in Hiroshima and Nagasaki up to 10,000 feet from GZ. [redacted].

4. Mean Areas of Effectiveness. MAE's were calculated for both cities as shown in Figure 31. The annular ring method used for computation of MAE's for structures and machinery was also used for utilities. Since Hiroshima had few industries in reinforced-concrete and steel-frame buildings within the damaged area, it was not possible to compute these MAE's. However, in the opinion of the Physical Damage Division, the MAE's and graphs shown in Figure 31 are considered sufficiently accurate for future prediction of utility damage resulting from attacks with atomic bombs. It should, however, be emphasized that the graph for utilities in reinforced-concrete buildings gives too high a value because of the building design described in paragraph 3f (1) above.

5. Recommendations. Utility installations above ground were vulnerable to attacks with atomic bombs; therefore as many as possible of the utility components should be carried in underground conduits; and transformers and switchboards placed above the ground should be protected with reinforced-concrete blast walls.

ATOMIC BOMBS

PLANT UTILITIES

HIROSHIMA - NAGASAKI

F (Fraction)			A (Area)	FA		
WF	SF	RC		WF	SF	RC
0.89	0.43	0.33	1	0.89	0.43	0.33
0.79	0.36	0.25	3	2.37	1.08	0.75
0.67	0.30	0.18	5	3.35	1.50	0.90
0.60	0.24	0.11	7	4.20	1.68	0.77
0.48	0.16	0.05	9	4.32	1.44	0.45
0.40	0.09	0.0	11	4.40	0.99	0.0
0.30	0.0	0.0	13	3.90	0.0	0.0
0.20	0.0	0.0	15	3.00	0.0	0.0
0.10	0.0	0.0	17	1.70	0.0	0.0
			ΣFA =	28.13	7.12	3.20

$MAE = \Sigma FA \times \pi \times 10^6$

MAE for	WF	SF	RC
1000's Sq Ft	88,300	22,300	10,000
Acres	2,027	512	229
Sq Mi	3.17	.80	0.358

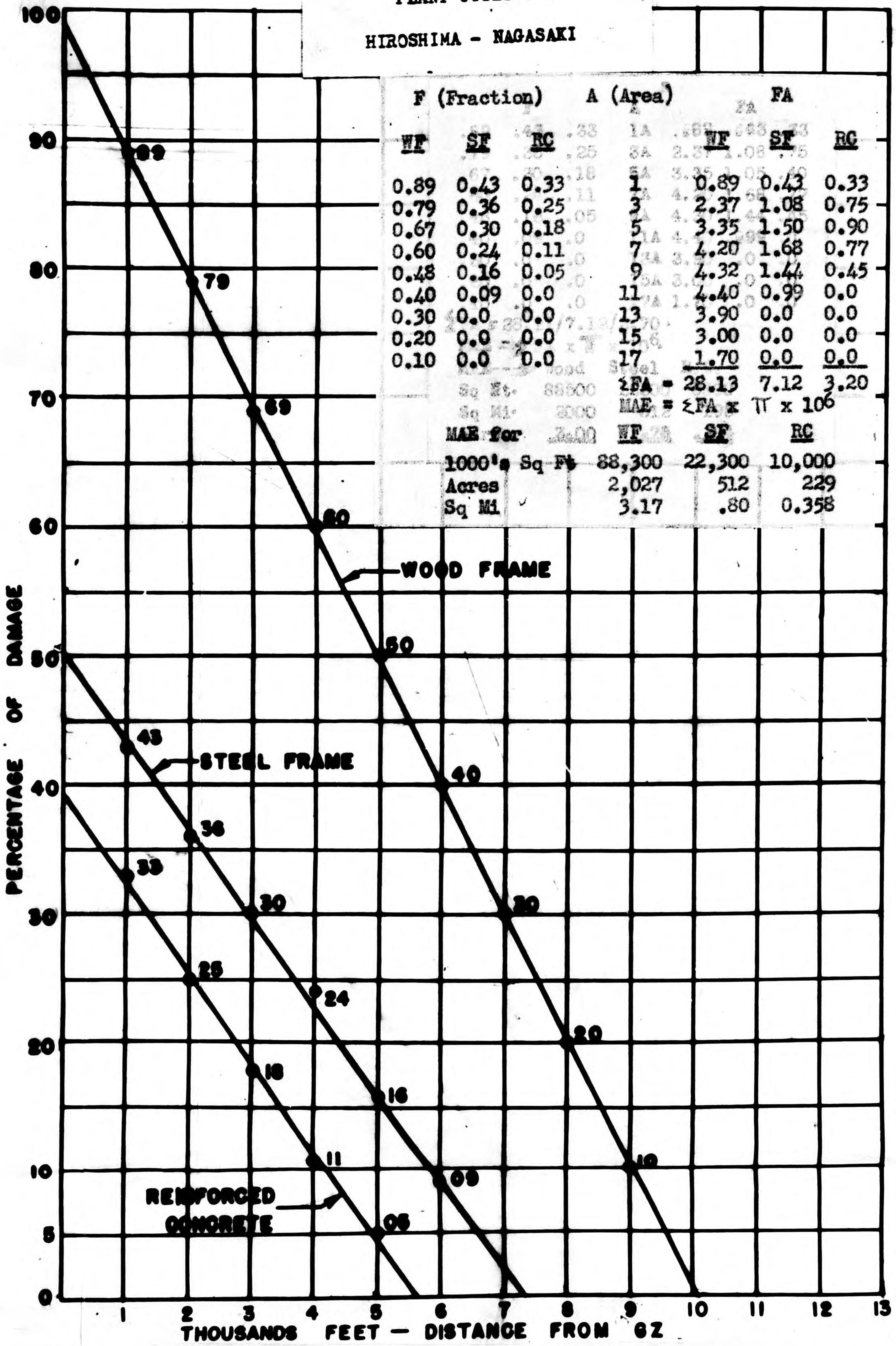

Fig.

Photo 120. Nagasaki, 2,500 feet from GZ. Switchboard and circuit breakers heavily damaged by blast.

Photo 121. Nagasaki, 2,500 feet from GZ. Transformers slightly damaged by debris.

Photo 122. Nagasaki, 3,600 feet from GZ, Takenokube Substation. Damage to three-circuit copper bus structure. Flash burns on poles.

Photo 123. Nagasaki, 3,600 feet from GZ, Takenokube Substation. Damage to 3.5-kv switch rack and first tower.

Photo 124. Nagasaki, 5,400 feet from GZ, Zenza Substation. Southeast corner of control and switch room.

Photo 125. Nagasaki, 5,400 feet from GZ, Zenza Substation. Controls, 3.5-kv busses and oil-circuit breakers.

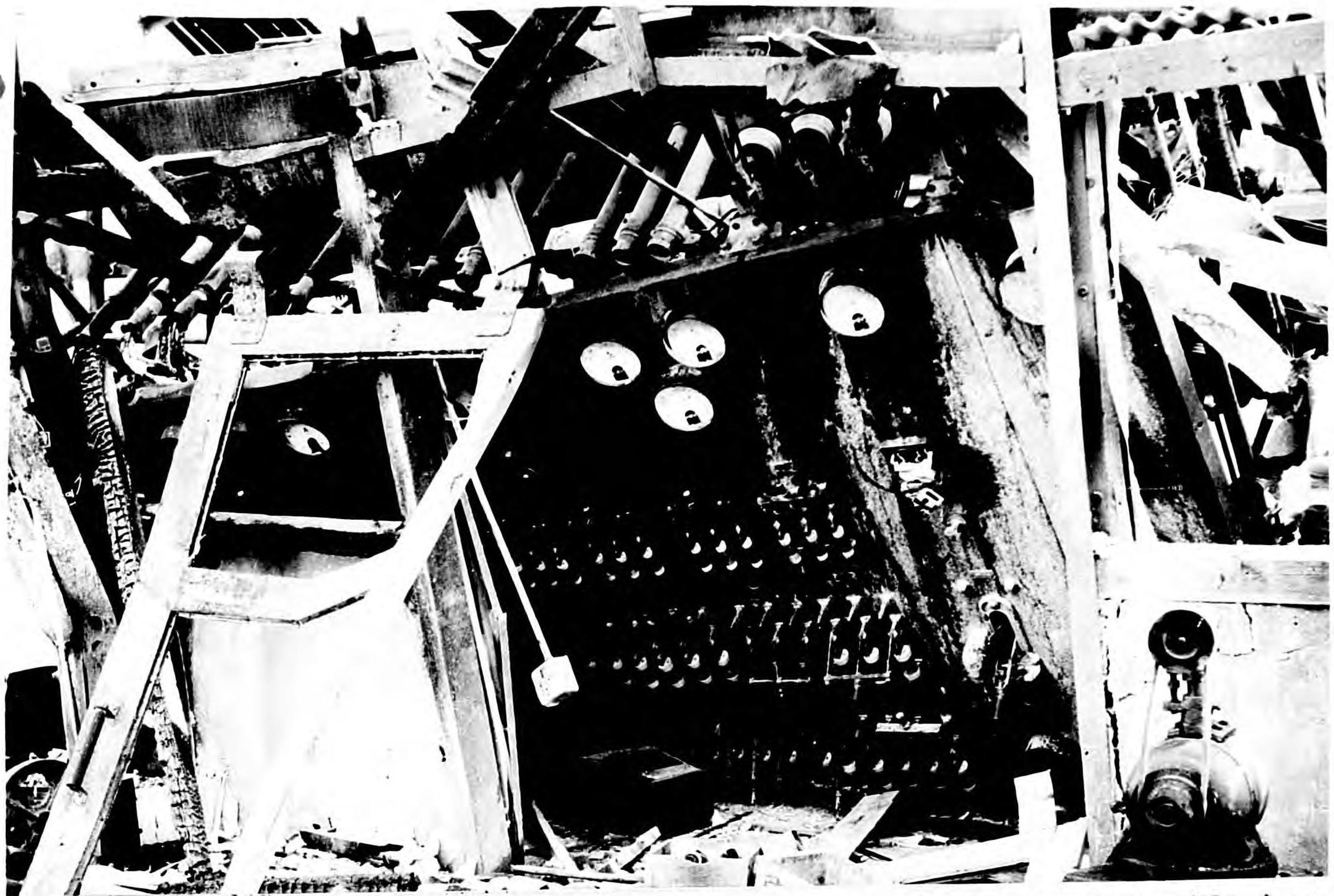

Photo 126. Nagasaki, 5,000 feet from GZ. Switchboard overturned by blast and damaged by fire.

Photo 127. Nagasaki, 4,000 feet from GZ. Transformers overturned and slightly damaged by blast.

Photo 128. Nagasaki, 2,000 feet from GZ. Electrical system destroyed by fire.

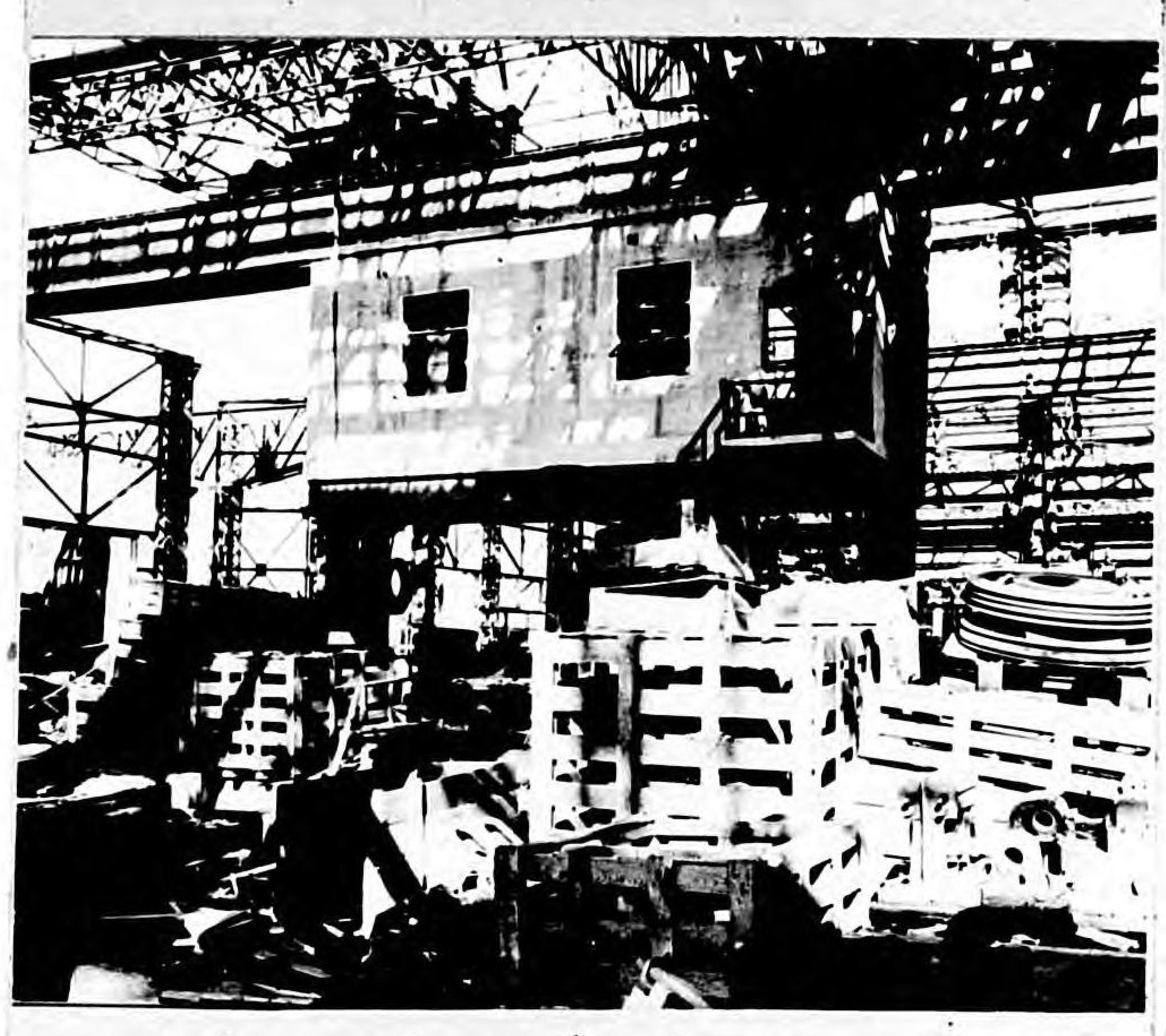

Photo 129. Nagasaki, 4,500 feet from GZ. Typical transformer switch house.

Photo 130. Nagasaki, 3,800 feet from GZ. Transformers overturned but undamaged by blast and debris.

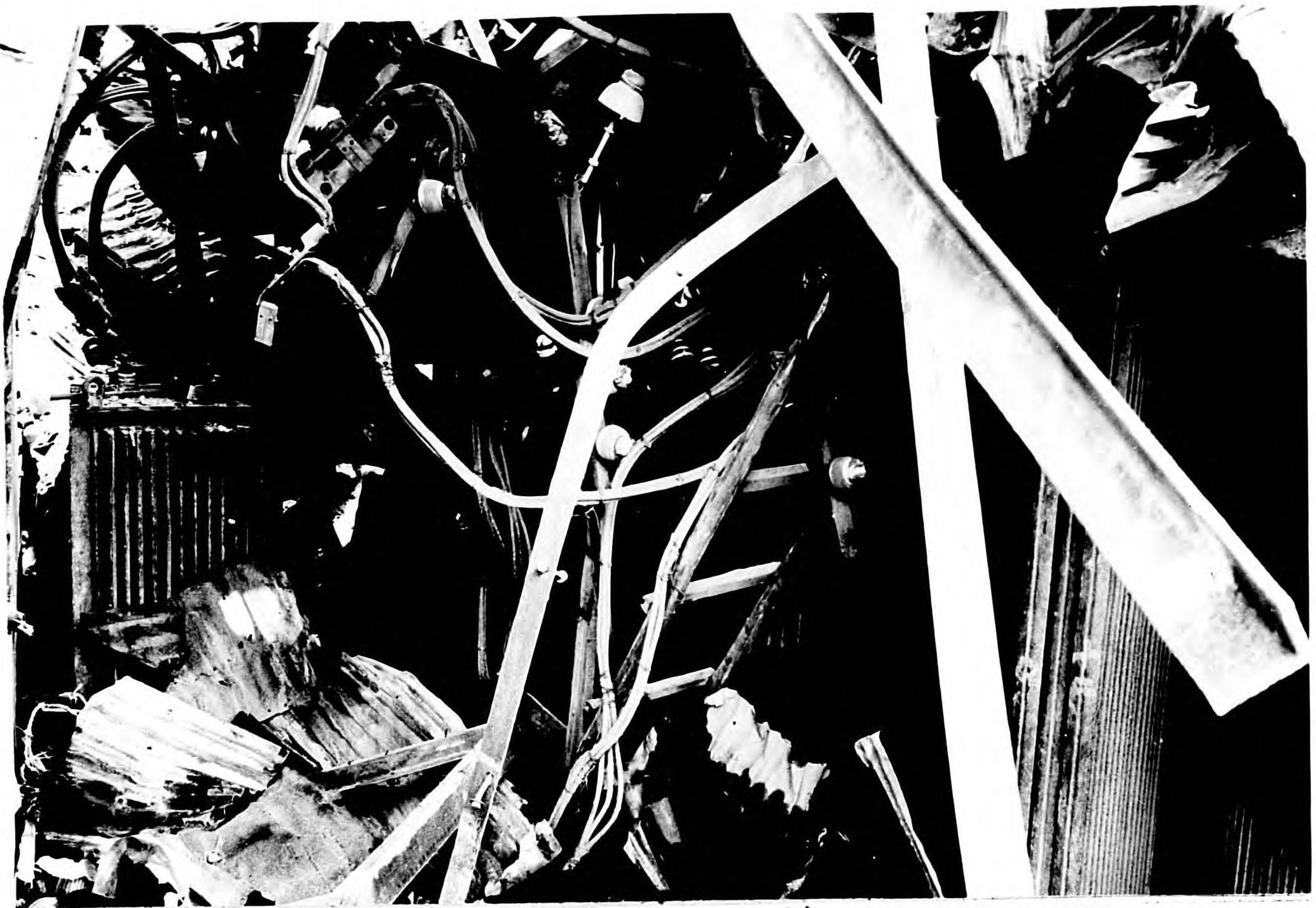

Photo 131. Nagasaki, 3,800 feet from GZ. Debris on transformers for electrical furnace.

Photo 132. Nagasaki, 3,800 feet from GZ. Bus structure damaged by blast.

Photo 133. Nagasaki, 3,400 feet from GZ. Typical blast damage to overhead wiring.

Photo 134. Nagasaki, 3,900 feet from GZ. Typical arrangement of electrical wiring.

Photo 135. Nagasaki, 3,700 feet from GZ. Radial driller on first floor damaged by debris and fire.

Photo 136. Nagasaki, 3,700 feet from GZ. Vertical miller damaged by fire.

Photo 137. Nagasaki, 3,700 feet from GZ. Electric wiring destroyed by blast, and machine tools slightly damaged by debris.

Photo 138. Nagasaki, 4,200 feet from GZ. Utilities destroyed by collapsed structure.

Photo 139. Nagasaki, 4,200 feet from GZ. Typical utility damage in steel-frame structure.

Photo 140. Nagasaki, 1,100 feet from GZ. Oxygen compressers heavily damaged by debris.

Photo 141. Nagasaki, 1,100 feet from GZ. Oxygen holder destroyed by blast and fire.

Photo 142. Nagasaki, 3,000 feet from GZ, Ohashi Gas Works. Destroyed tank structure.

Photo 143. Nagasaki, 3,000 feet from GZ, Ohashi Gas Works. Damaged tank top of gas holder.

Chap VI

CHAPTER VI

THE ATOMIC BOMBS

A. FOREWORD

1. The advent of the atomic bomb opened up an entirely new field in the study of the destructive power of aerial weapons. Much data relative to the characteristics and effectiveness of conventional high-explosive and incendiary bombs had been collected and evaluated as a result of experiences gained in the European theatre, so that the AAF was able to make remunerative and effective attacks on Japanese targets. But here was an entirely new and revolutionary weapon which possessed the usual characteristics of blast, although many times more powerful, and also introduced new elements - heat and radiation. The study of the effects of the atomic bombs on Hiroshima and Nagasaki with respect to physical damage to structures and their contents, utilities, and transportation has been a fascinating one, as well as one fertile in information which will be of inestimable value to planners in many fields of endeavor.

2. One of the purposes of this division was to establish in proper perspective the relationship of the atomic bomb to other weapons by comparisons of relative effectiveness. All in all, the atomic bomb was so much more destructive for its size and weight than any other known bomb that any attempt to minimize it would be not only futile but impossible. It is believed, however, that the colorful and dire predictions of early observers, predictions based on cursory and incomplete study, can be toned down considerably in the light of current, available information. For example, it is interesting to note that the wasted

areas of Hiroshima and Nagasaki did not differ materially, at least in outward appearances, from those of Japanese cities, such as Tokyo, ravaged by incendiary attacks. And in Germany the ruins of such cities as Hamburg and Essen, attacked by both high-explosive and incendiary bombs, differed only in profile because of the type of construction, but the results achieved were the same - total damage; but how these cities got that way as compared with Nagasaki and Hiroshima is still another matter which is discussed in the following pages and in the final report on the European Theatre (PDD Report 68).

3. In many respects, the type of physical damage caused by the atomic bomb was not unusual and was what might well be expected, considering the established physical laws governing the effects of blast pressures. But the degree and extent of this kind of damage were so widespread that many new factors will have to be considered in future calculations. In other respects, the heat generated by the atomic bomb explosion exceeded the limit of ordinary human comprehension. To those of us who are accustomed to thinking only in terms of weather temperatures, the millions of degrees centigrade at the bomb's core represents an astronomical figure; and even the 3,000° to 9,000° centigrade temperature estimated to have hit the atomic areas is fantastic. Its effects, however, definitely establish the stark reality of the situation, leaving no doubt in the observer's mind. Likewise, free neutrons and high-frequency radiations such as gamma rays were something new, at least in warfare. Their effects on the human body and on soil and vegetation are the subject of another Division of the Survey.

4. Study and further experimentation will together point to what is to be done in the future to counteract the effects of the atomic bomb. In the meantime any and all information regarding the bomb's characteristics, behavior, and effects on life, morale, industry, business, utilities, and all aspects of economic endeavor is extremely important to military and civilian planners in their efforts to evaluate the bomb and to provide efficacious counter measures.

5. This report makes no attempt to pass judgment on the over-all effectiveness of the atomic bomb, its purpose being solely to give as complete a summary as possible of the physical damage suffered by the stricken cities as a result of both the direct and indirect effects of the atomic forces. (The complete story of Hiroshima will be found in PDD Report 69, and of Nagasaki in PDD Report 70). Résumés of findings on damage to buildings of all existing types - industrial, commercial, and residential - are included herein, together with certain conclusions concerning the relative degrees of resistance, inherent in the several types, to the direct and indirect results of the atomic bomb. Likewise, building contents vulnerability and degree of damage in relation to types of construction are discussed. Considerable space is devoted to fire since it resulted from both direct and indirect causes and was the source of a large proportion of the physical damage. Other subjects studied and reported on are: damage to machine tools, utilities, bridges, stacks, and services.

B. PRE-ATTACK CONDITIONS

1. Hiroshima

a. The City. Hiroshima, located in the southwestern area of the principal Japanese island of Honshu and at the northwestern corner of the Inland Sea, was an important, modern, administrative, communications, and military center. The seventh largest city in Japan, it had had a wartime peak population of 380,000, but, as the result of several evacuations, that figure had been reduced to an estimated 245,000 by 6 August 1945, the date of the atomic-bomb attack. The city had developed on the delta of the Ota River and spread over seven finger-like islands formed by six river channels (Figure 32). Except for four small, rocky formations, only one of which was as high [redacted] as 220 feet [redacted], the delta was uniformly flat and about 10 feet above sea level. The evenly exposed area stretched 6,500 feet in all directions from the heart of the city, ~~so that~~ but within the city boundaries there were approximately 26.5 square miles.

b. Built-upness. Densely built-up areas (over 40 per cent of plan area) or moderately built-up areas (20 to 40 per cent of plan area) extended for 23,000 feet on the north-south axis and 17,000 feet on the east-west. Around the central core of the city in a concentric area with a minimum radius of 6,000 feet occurred the greatest density of dwellings and wood-frame structures. In addition, there were located in this area many wall-bearing brick buildings and fewer steel-frame structures which were representative of the post-1923, earthquake-resistant design. Interspersed among these buildings were the low,

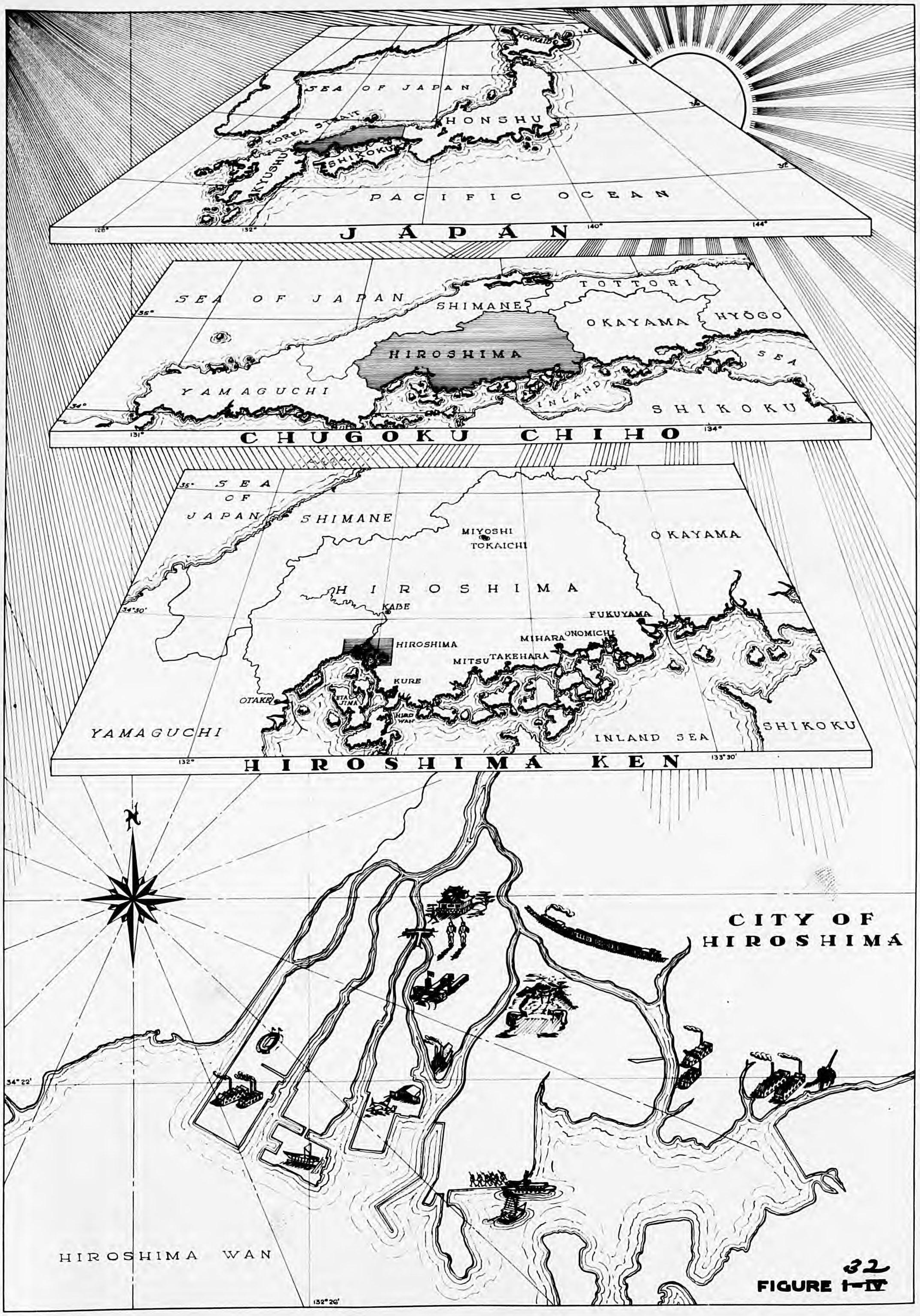

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FIGURE I-IV

flimsily-built shops, dwellings, and offices of typical Japanese wood design and construction.

c. Use. The central area of 6,000-foot radius comprised the principal commercial section of the city, together with large parts of the residential and military sections, but there were no industries of appreciable size nearer than 8,900 feet to the city center, the main industries being located mostly on the eastern perimeter of the city or on the southern tips of the islands. Seventy-five per cent of the 245,000 inhabitants at the time of the attack were in the congested 4-square-mile city center, which gave a population density of 46,000 persons per square mile.

d. Vulnerability. As can be readily seen from the foregoing, Hiroshima had no natural barriers to protect it from the widespread effects of the atomic bomb, and that fact coupled with population density, flimsy construction, and building congestion, made it a choice target for maximum results. (Photos 144-152)

e. Pre-Attack Sequence. The air-raid "alert" (first audible public warning) was sounded at 0720 on 6 August 1945. It was the general policy in Japan at the time not to give the air-raid "alarm" unless planes appeared in force, and, as only three aircraft were seen in the sky, the "all clear" (release-from-alert) was sounded at approximately 0740, whereupon the people resumed their customary daily tasks and practically no one was in shelters. Because of the time of day, many residences had fires for the purpose of cooking meals; most of the industrial workers were already at the factories; and many

Photo 144.

Photo 145.

Photo 146.

Views of over-all damage to Hiroshima.

Photo 147.

Photo 148.

Photo 149.

Views of over-all damage to Hiroshima.

Photo 150.

Photo 151.

Photo 152.

Views of over-all damage to Hiroshima.

professional men and commercial employees were on the way to their offices or businesses, so that traffic was comparatively heavy. Thus the scene was set with all conditions favorable for maximum casualties and damage when the bomb exploded in the air shortly after 0800.

2. Nagasaki

a. The City. Nagasaki was located on the western coast of Kyushu island. It lay on a narrow coastal strip encircling a long, narrow bay and extended up two river valleys, one to the north (Urakami), the other to the northeast (Nakashima), the two being separated by a mountain spur. An important industrial city, its greatest population during the war had been 288,000 but it had dropped to 230,000 on 9 August 1945, the date of the atomic-bomb attack.

b. Built-upness. The main residential and commercial districts were intermingled in the two river valleys. The metropolitan area of the city comprised about 35 square miles, of which only 3.8 square miles constituted the heavily built-up portion. Seventy per cent of the latter was 30 per cent or more built up. Population density in the 3.8-square-mile area was in the neighborhood of ~~70,000~~ 60,500 per square mile.

c. Use. Unlike the situation in Hiroshima where the large industries were on the fringe of the city, the industrial zone of Nagasaki was located in the Urakami River valley which averaged three-quarters of a mile in width; the Nakashima valley contained the main commercial and residential areas.

d. Vulnerability. Compared with Hiroshima, the topographical features of Nagasaki with its intervening hills ~~offered~~ offended protection from widespread blast effects of the atomic bomb, and also served to prevent fire spread. This statement is confirmed by the fact that, although the bomb which exploded over Nagasaki was reported to have been more powerful and was detonated closer to the ground, the damage was less widespread but of greater intensity within the area affected. On the other hand, the density of population, the typical flimsy construction, building congestion and concentration of industry in one valley were all factors favorable to effective atomic-bomb damage. (Photos 153-157)

e. Pre-Attack Sequence. The USAAF had been sending reconnaissance planes in small numbers over the Nagasaki area daily for several weeks prior to 9 August. The "alert" would be sounded and, pursuant to local variations of shelter procedure, the aged, sick, women, children and others not engaged in essential activities would go to shelters. There they would wait expectantly, but nothing would happen. This was repeated day after day, not once but several times. On the day immediately preceding the atomic-bomb attack, people had been in the shelters for two hours to no purpose, and had then been released. A spirit of carelessness developed and it proved to be their undoing. On the ninth of August, a small flight (2 planes) to which the people had become accustomed appeared over the city - just other reconnaissance ships. The "alert" was sounded. Why bother going to shelter? Nothing would happen. The "alarm" howled on the sirens, to be followed in a short time by the "release-from-alarm" which merely confirmed the belief

Photos 153 (above) and 154 (below). Aerial photos of devastated Nagasaki showing location of Ground Zero.

Photo 156. Nagasaki, looking northwest from Urakami River bridge, approximately 1,600 feet from GZ. This area, containing small and unimportant structures of wood, steel frame, brick, and reinforced concrete, was completely devastated by blast and fire.

Photo 157. Nagasaki, looking south approximately 1,600 feet from GZ. Brick plant: 10-foot high, brick-vaulted roofs totally damaged by blast and fire, 34-inch brick walls badly cracked.

Photo 158. Nagasaki. Area west of railroad and highway in fork of Urakami River. Concrete stack, four feet in diameter and 70 feet high, fell to northwest. Brick kiln at left of photo.

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of the population that there was no danger. And then at 1102 came the catastrophic detonation.

C. THE ATTACKS

1. The first atomic bombs to be used for military purposes were dropped on the ill-fated cities of Hiroshima and Nagasaki and inaugurated not only a totally new concept of aerial warfare, but provided a basis for the analysis of bomb damage and effects on a plane which had not been heretofore considered. For the first time, instead of studying the damaging effects of a number of missiles on individual structures, consideration had to be given to entire blocks of buildings wholly or

JAPANESE Page 296

The weather at Hiroshima was clear at the time of the attack; at Nagasaki, however, although accurate weather reports as of the time of attack are not available, the AAF estimates that the target was covered by 8/10 stratocumulus clouds, the base of which is normally above 2,000-3,000 feet and the top 4,000-5,000 feet above ground, respectively. Otherwise, the two attacks were made under similar circumstances with respect to winds of low velocity and to conditions on the ground.

6 August 1945; the second on Nagasaki at 1102 hours 9 August 1945. The

~~two attacks were made under somewhat similar circumstances, both as to weather which was clear over the two targets with winds of low velocities, and as to conditions on the ground.~~ Insert Both cities had been subjected to previous high-explosive attacks which had caused relatively little damage; residents had become accustomed to the presence of reconnaissance planes over their cities; no large groups of planes had been reported to indicate that any large-scale attacks were imminent; air-raid alarms had been sounded, then cancelled; few persons were in shelters; defense and protective forces were not fully manned; and in of the population that there was no danger. And then at 1102 came the catastrophic detonation.

C. THE ATTACKS

1. The first atomic bombs to be used for military purposes were dropped on the ill-fated cities of Hiroshima and Nagasaki and inaugurated not only a totally new concept of aerial warfare, but provided a basis for the analysis of bomb damage and effects on a plane which had not been heretofore considered. For the first time, instead of studying the damaging effects of a number of missiles on individual structures, consideration had to be given to entire blocks of buildings wholly or partly demolished, some appearing to have been flattened as though by a giant hand, to widespread areas of destruction and desolation measured in square miles rather than in square feet or acres; and to large, fire-swept urban areas, all resulting from the air burst of one bomb.

2. The first atomic bomb was dropped on Hiroshima at 0816 hours 6 August 1945; the second on Nagasaki at 1102 hours 9 August 1945. ~~The two attacks were made under somewhat similar circumstances, both as to weather which was clear over the two targets with winds of low velocities, and as to conditions on the ground.~~ Insert Both cities had been subjected to previous high-explosive attacks which had caused relatively little damage; residents had become accustomed to the presence of reconnaissance planes over their cities; no large groups of planes had been reported to indicate that any large-scale attacks were imminent; air-raid alarms had been sounded, then cancelled; few persons were in shelters; defense and protective forces were not fully manned; and in

neither instance were either the citizens or responsible military and government officials in any way prepared for the sudden, violent, catastrophic onslaught from the skies.

3. Both bombs detonated at certain heights in the air. The explosions were characterized by a blinding flash, followed by an intense heat wave, and crushing blast pressures. Scientists estimated that the detonation of the atomic bomb, lasting only a millionth of a second, created a ball of fire hotter than the center of the sun (70,000,000°C), and released radiations ranging from beyond the infra-red, through the visible spectrum, and into the ultra-violet and gamma rays. The Nagasaki bomb was reported to be an improved and more powerful version of the weapon used in the Hiroshima attack, and was detonated at a slightly lower altitude.

D. EFFECTS

1. The results of the atomic-bomb explosions which immediately paralyzed the facilities and normal life of two cities were various and, in many instances, as spectacular as the bomb itself. Outstanding among these were the extreme distances at which blast damage occurred; the wide area of total damage; the ignition and scorching of combustible materials and the searing of noncombustibles at great distances.

a. Buildings. In Hiroshima approximately 60,000 of an estimated total of 90,000 buildings over an area of 9.5 square miles were totally or heavily damaged. Dwellings and structures of Nagasaki were demolished throughout an area of 1.8 square miles, or within a radius of 5/8 mile from Ground Zero, and other structures suffered varying

4 Insert

degrees of damage within a 2½-mile radius. Superficial and minor damage

JAPANESE Page 298 (top)

The The lesser area of damage in Nagasaki in spite of the greater destructive force of the bomb may be attributed to the topographical features of the city which confined the blast pressure to a comparatively narrow corridor.

6,500 feet from Ground Zero. The degree of damage and the number of machine tools affected depended largely on the types of structures in which they were housed. Damage resulted from blast effects, debris, fire, and exposure to the elements.

c. <u>Bridges</u>. The timber bridges in both cities were the most heavily damaged by blast and fire. Those of steel and concrete were affected to a lesser degree, and heavy concrete bridges were the least affected of any. Some steel bridges were collapsed, and others were structurally damaged. At Hiroshima, in many cases, bridges which were not seriously damaged could not be utilized because of masses of debris from adjacent buildings which clogged the approaches.

d. <u>Stacks</u>. Reinforced-concrete stacks were found to be generally resistant to blast effects, only four of approximately 30 within 6,000 feet of Ground Zero having been damaged in Nagasaki. All steel and brick stacks within the same area were totally damaged. In Hiroshima, 45 per cent of all stacks within a radius of 1.6 miles were damaged beyond use.

e. <u>Public Utilities</u>. All public utilities were damaged and completely disrupted. Both cities were temporarily without transportation, degrees of damage within a 2½-mile radius. Superficial and minor damage was experienced up to 8 miles ~~at Hiroshima, and as far as [illegible] at Nagasaki~~ in both cities.

b. Machine Tools. Machine tools in Hiroshima were totally or heavily damaged throughout an area exceeding four square miles. In Nagasaki various degrees of damage to machine tools extended up to 6,500 feet from Ground Zero. The degree of damage and the number of machine tools affected depended largely on the types of structures in which they were housed. Damage resulted from blast effects, debris, fire, and exposure to the elements.

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d. Stacks. Reinforced-concrete stacks were found to be generally resistant to blast effects, only four of approximately 30 within 6,000 feet of Ground Zero having been damaged in Nagasaki. All steel and brick stacks within the same area were totally damaged. In Hiroshima, 45 per cent of all stacks within a radius of 1.6 miles were damaged beyond use.

e. Public Utilities. All public utilities were damaged and completely disrupted. Both cities were temporarily without transportation, electricity, communications, gas, water, and sewers. Within a period of several days, however, some of these services, such as railroad and street railway transportation, electric power, and water supply, were available to a limited degree in certain areas, mostly for essential use.

f. Fire. Fires, caused by radiant heat from the detonation of the bomb, as well as by electrical short circuits and as a result of inflammable debris falling on or upsetting open-flame devices, accounted for large areas of damage in both cities. An area of 4.4 square miles was burned over in Hiroshima, and in Nagasaki approximately one-third of the densely built-up area of (3.8 square miles) was swept by flames. Fire defenses in both cities were considerably limited as the initial bomb blast had seriously crippled the fire-fighting organizations, damaged equipment, and killed or injured personnel.

E. DAMAGE TO BUILDINGS

1. Building Types. Buildings in both Hiroshima and Nagasaki ranged from modern, reinforced-concrete structures and steel-frame industrial buildings to wood-frame buildings and the typical Japanese dwellings which were entirely of wood construction except for tile roof covering. Some of the commercial buildings were of reinforced concrete of excellent material and earthquake-resistant design. Those of multistory construction and aseismic design were usually heavier and stronger than similar types in the United States. Quality of concrete and workmanship varied considerably, however, and some buildings of substandard design and construction were found. There were other buildings

of load-bearing brick-wall construction, and some which had reinforced-concrete frames. The industrial-type buildings were generally of steel-frame construction, single-story, having either saw-tooth or monitor-top roofs. These buildings were usually covered with corrugated-asbestos or corrugated-metal roofing and siding. Despite the encouragement of Western construction practices and the adoption by the Japanese government of aseismic design for large buildings, the shortage of critical building materials and the lack of enforcement of the building code resulted in the predominance of wood-frame and wood-pole construction over all other types in every city. The wood-frame buildings, for the most part, comprised dwellings, combination shop-dwellings, and small commercial and industrial buildings. Typical wood buildings in Japan had light frames, relatively heavy roofs supported by slender columns, and poorly designed joints. Buildings of this type were, of course, highly vulnerable to fire and blast.

2. Extent of Damage

a. Structural Damage. Widespread structural damage was found in Hiroshima up to between 6,000 and 7,000 feet from Ground Zero and up to a maximum of 11,000 feet in Nagasaki. The area of damage in Nagasaki, however, was not uniform as it was in Hiroshima. The bomb in the latter city detonated over its center where the land was level; at Nagasaki, it detonated over a valley away from the center of the city and the blast travelled along the valley in both directions. The degree of damage at Nagasaki was greater than at Hiroshima, although the actual area in which damage occurred was smaller. At Nagasaki 30.7

per cent or 1.8 square miles of the built-up area of the city suffered structural damage; in Hiroshima, 69 per cent of the city's buildings over an area of 9.5 square miles were totally or heavily damaged. In comparing the extent of damage among the several types of buildings in the two cities, it must be considered that there was a marked difference between the areas affected by each bomb. In Hiroshima, for example, the area under the point of detonation comprised a domestic and commercial zone where there were many houses but few industrial buildings; the bomb at Nagasaki was dropped over a zone that was both domestic and industrial, but with numerous industrial buildings and fewer dwellings than the bomb-affected area of Hiroshima. In fact, the bombed area of Nagasaki contained the most strongly built structures in the city. Although the degree of damage in both cities decreased as the distance from Ground Zero increased, the rate of decrease was not uniform in similar types of buildings. This lack of uniformity resulted largely from the differences in design and quality of workmanship in similar types of buildings. Further, it was often impossible to obtain a reliable estimate of the damage which might have been expected at various distances from the point of detonation when there was an insufficient number of buildings of the same general types exposed to the effects of the bomb at similar distances from Ground Zero.

(1) Reinforced-Concrete Buildings. The strongly built, heavy, multi-story, reinforced-concrete and concrete-frame buildings were by far the most resistive to the blast effects of the atomic bomb. These buildings

were heavily damaged only in an area relatively near the point of bomb detonation. A much higher percentage of buildings of similar construction but of lighter materials and inferior design was totally or heavily damaged at greater distances. At Nagasaki, 9.5 per cent of the floor area of reinforced-concrete buildings in the area between 2,000 and 3,000 feet from Ground Zero, the majority of which were of excellent material and earthquake-resistive design, was totally or structurally damaged. In the area between 4,000 and 5,000 feet from Ground Zero, however, 56 per cent of the reinforced-concrete buildings, primarily of single-story, light shell-type construction, suffered total or heavy damage. Differences between the physical characteristics of the terrain and types of construction in the two cities, and possibly differences between the forces created by the two detonations accounted for variations in extent of structural damage to this type of building. Equivalent blast effects were found in Nagasaki over greater areas. Structural damage to reinforced-concrete buildings in that city occurred within an area of 0.43 square mile, compared with an area of 0.05 square mile of similar heavy damage in Hiroshima. It is believed that more widespread damage to this type of building would have resulted from detonation of the atomic bomb at a lower altitude without seriously affecting the extent of damage to other classes of buildings. (Photos 160-161).

(2) Steel-Frame Buildings. Single-story, light, steel-frame industrial buildings were heavily damaged throughout areas of approximately equal size in both cities. Superficial damage to structures of this type covered an area of 3.4 miles at Hiroshima; 3.3 miles at Nagasaki. There were no heavy, steel-frame buildings in Hiroshima, and damage to this class of structures could be studied only at Nagasaki where structural damage extended over an area of 1.8 square miles. Steel-frame buildings covered with corrugated-asbestos siding and roofing generally suffered less structural damage than those buildings having corrugated-iron or sheet-metal covering. The blast effects immediately ripped off or crumbled the asbestos material, leaving no wide surfaces exposed against which damaging blast pressure could be exerted and transmitted to the framework. Metal siding, however, transferred pressure to the structural members, causing distortion or general collapse. (Photos 162, 164).

(3) Load-Bearing Brick-Wall Buildings. Buildings of load-bearing brick-wall construction were extremely vulnerable to blast and therefore suffered heavily from

the effects of the atomic bomb. Multi-story brick buildings, which were studied only at Hiroshima, were structurally damaged within an area of 3.6 square miles. Single-story brick buildings were damaged in the same city within an area of 6 square miles, and within an area of 8.1 square miles in Nagasaki. In Hiroshima, collapse or serious cracking of walls occurred in buildings having 24- to 27-inch walls up to 3,700 feet; and in buildings having 9-inch walls, similar damage was inflicted up to 8,200 feet from Ground Zero. In Nagasaki 100 per cent of the floor area of the brick buildings up to 3,000 feet from Ground Zero suffered total or heavy structural damage. Between 3,000 and 7,000 feet, over 75 per cent of the floor area of those studied was similarly damaged, and various degrees of structural damage extended as far as 11,000 feet from Ground Zero. Many of the brick buildings which were heavily damaged at great distances from Ground Zero were set somewhat apart from other structures and consequently had little shielding from blast, (Photos 158-159, 165).

(4) Wood-Frame Buildings. Wood-frame industrial and commercial buildings in Hiroshima were structurally damaged up to 7,300 feet from Ground Zero, and within an area of 8.5 square miles. In Nagasaki, buildings

Photo 158. Nagasaki. Urakami cathedral. Brick and stone building, 1,800 feet from GZ, totally damaged by blast. Concrete dome from west tower resting in center of debris.

Photo 159. Same as Photo 158, but looking northwest. Remains of south wall.

Photo 160. Nagasaki, school for blind and dumb, reinforced-concrete structure, 1,900 feet from GZ heavily damaged by blast. North wall broken and leaning to north at third-floor line.

Photo 161. Same as Photo 160. Exposed reinforcing steel in column at third-floor level.

Photo 16~~3~~2. Hiroshima. Shimomura Watch Shop, 2,000 feet from GZ. Second story of steel-frame building resting on ground. Columns and walls of first story at right. Combustible debris burned.

Photo 162

Photo 163. Hiroshima, 6,500 feet from GZ. Wood-frame, light-engineering shop structurally damaged by blast and then consumed by fire.

Photo 164. Nagasaki. Wood and steel-frame building of Standard-Vacuum Oil Works, 6,500 feet from GZ, totally damaged by blast and fire.

Photo 165. Nagasaki. Load-bearing brick wall and wood-frame construction of Standard-Vacuum Works totally damaged by blast.

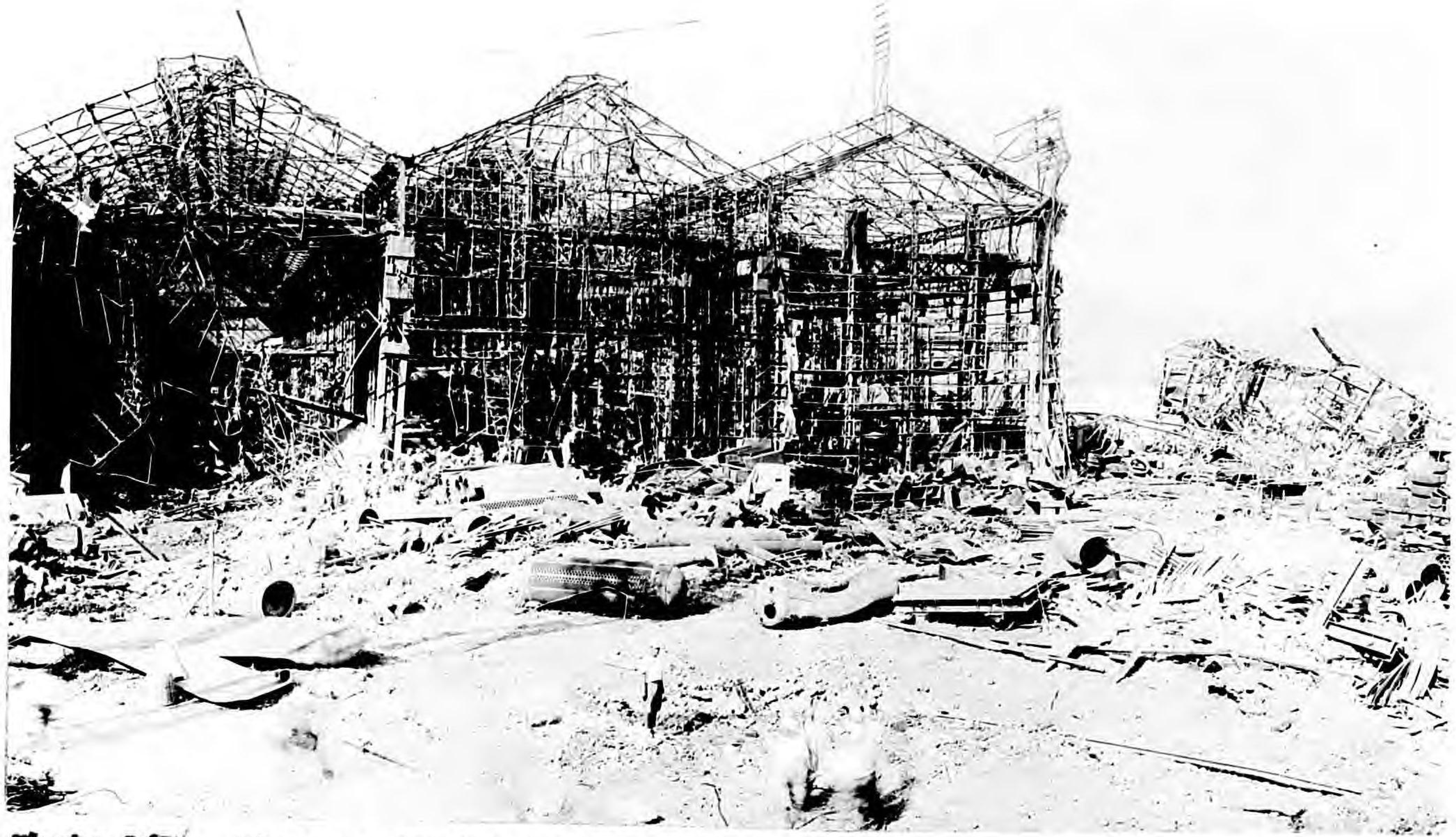


Photo 167. Akunoura Engine Works. Steel-frame boiler shop which suffered heavy structural and superficial damage from high-explosive bombs, but little additional damage from atomic bomb.

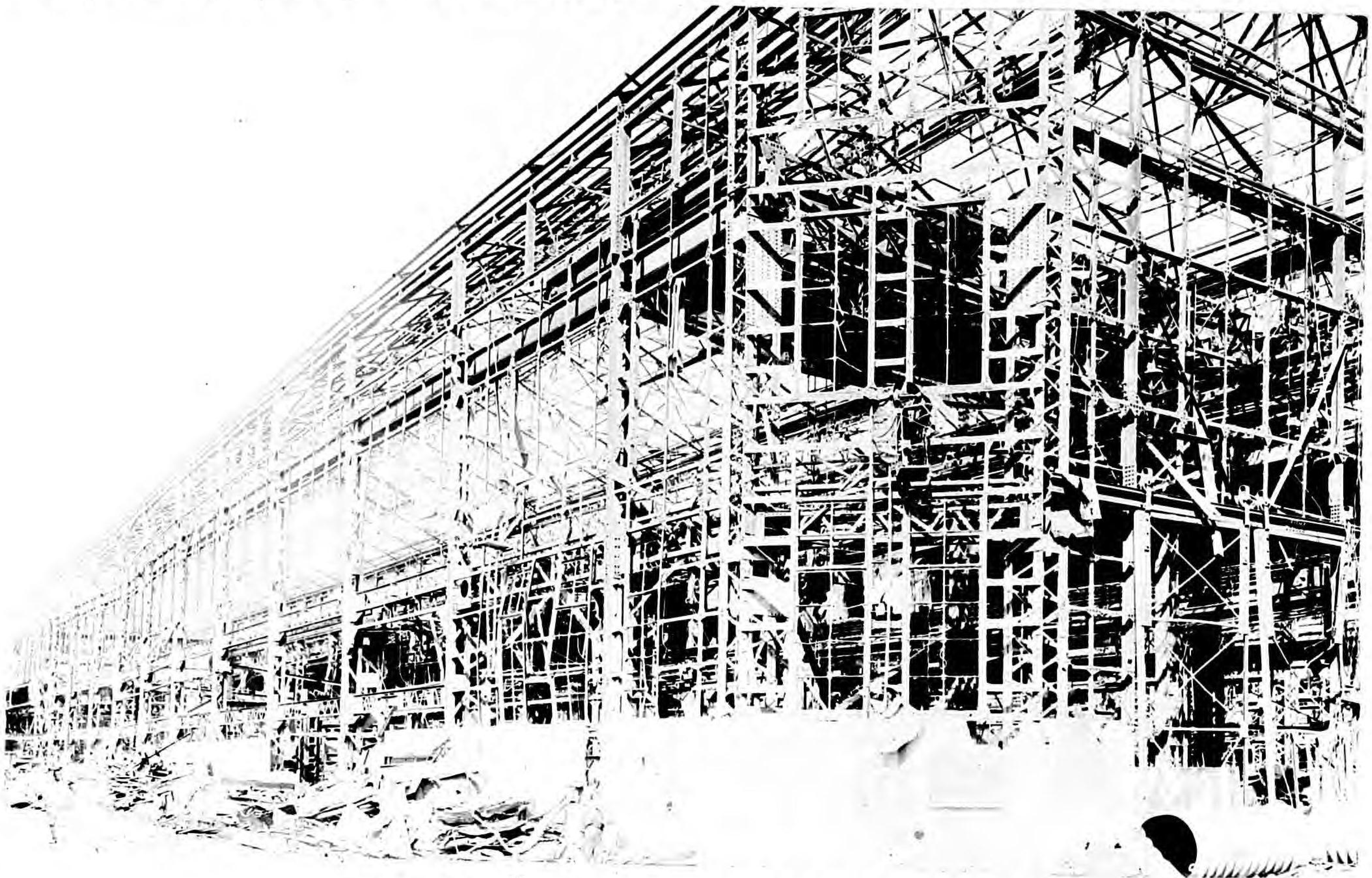


Photo 168. Nagasaki. Same as Photo 167.

buildings of similar construction were structurally damaged within a radius of 10,000 feet from Ground Zero, or within an area of 9.9 square miles. These buildings were generally of inferior construction and design. Supporting members and columns were easily buckled by blast pressure on roofs, leading to mass distortion and collapse of framework. Structural damage to wood-frame buildings as a result of blast generally extended well beyond the area of fire damage. Wood-frame and all-wood domestic buildings in Hiroshima were totally or heavily damaged throughout an area of 6 square miles; in Nagasaki, throughout an area of 7.5 square miles. (Photos 163-165).

(5) Mean Areas of Effectiveness (MAE's). No great significance can be attached to the areas of structural damage to any one type of building without considering the total area of the buildings of that type exposed to the blast. A better estimate of the bomb's effectiveness against structures of certain types can be obtained by computing the mean areas of effectiveness (MAE's) and making comparisons at the two cities on that basis. To obtain a sufficient number of buildings with structural damage for comparison in the two cities, it was necessary to group various buildings of the same or similar type of construction. These

groups lack the greater refinement of classification which is found in the data for high-explosive bombs. The categories of buildings compared at Hiroshima and Nagasaki, however, were essentially the same and reacted similarly to blast. The mean areas of effectiveness of the atomic bomb for structural damage around Ground Zero and the radii of the MAE's for the different classes of buildings in both cities are shown in Table 37. To find the MAE's for the various building categories the annular-ring method was used, except for wood dwellings in Group 8. The MAE's for the latter group were computed by the average-circle method. The MAE's comprehend structural damage caused by blast alone, fire and blast combined, and fire alone. The following paragraph of this section (Paragraph 3) indicates the percentages of damage resulting from those causes. In comparing MAE's at Hiroshima with those at Nagasaki, it should be understood that the figures are for two bombs whose heights of detonation differed by some 15 per cent, that at Nagasaki was the lower bomb which was reported to have been an improved and more powerful version of the atomic bomb dropped over Hiroshima. A comparison of the building groups for which there were data for both cities indicated that the more powerful Nagasaki bomb produced larger mean areas of effectiveness. The MAE for Group 2 of Hiroshima is about 10 per cent of that for Nagasaki. Some of the buildings in Group 2 at Nagasaki, however, were more vulnerable to blast because of their position on or near the ridge of the valley. Group 4 has about the same value for both cities, perhaps explained by the relatively greater extent of shielding by other buildings at Nagasaki. The MAE's at Hiroshima for Groups 6 and 7 are about 75 per cent and 85 per cent, respectively, of those for Nagasaki. In Group 8, the MAE for Hiroshima is 80 per cent of that for Nagasaki. The MAE's at Hiroshima and Nagasaki for Group 7 are larger than those for Group 8 because the buildings in the latter group were better constructed and probably more shielded from the blast. The extent of structural damage by blast to the different types of buildings, as well as the MAE for each type, is shown graphically in Figures 33 through 37. For almost every category of building the fraction of damage was greater for Nagasaki than for Hiroshima at corresponding distances from Ground Zero.

b. Superficial Damage. Superficial damage, consisting of the stripping of wall and roof covering, and the removal of light partitions, windown glass and frames, extended to as far as 7 miles from Ground Zero.

TABLE ~~1~~ 37

MEAN AREAS OF EFFECTIVENESS (MAE'S) FOR HIROSHIMA AND NAGASAKI

Building Group	Description of Building Type	Total Floor Area to Limit of Structural Damage (1000's of sq ft)	Total Floor Area of Structural Damage (1000's of sq ft)	Mean Area of Effectiveness (square miles)	Radius of Mean Area of Effectiveness (feet)
(1) Hiroshima	Multi-story, earthquake-resistant buildings only	597	34	0.03	500
Nagasaki		----	----	----	----
(2) Hiroshima	Multi-story, steel- and reinforced-concrete-frame (Including earthquake-and-non-earthquake-resistant buildings)	637	54	0.05	700
Nagasaki		694	121	0.43	2000
(3) Hiroshima	One-story, heavy, steel-frame	----	----	----	----
Nagasaki		1138	436	1.8	4000
(4) Hiroshima	One-story, light, steel-frame	94	51	3.4	5500
Nagasaki		741	484	3.3	5400
(5) Hiroshima	Multi-story, load-bearing brick-wall	189	158	3.6	5700
Nagasaki		----	----	----	----
(6) Hiroshima	One-story, load-bearing brick-wall	283	169	6.0	7300
Nagasaki		390	246	8.1	8500
(7) Hiroshima	Wood-frame, industrial-commercial	523	154	8.5	8700
Nagasaki		1475	1126	9.9	9400
(8) Hiroshima	Wood-frame domestic	----	----	6.0	7300
Nagasaki		----	----	7.5	8200

HIROSHIMA						AREAS IN 1000'S OF SQ.FT. NAGASAKI		
ALL STEEL- & REINF.-CONC.-FRAME BLDGS.			EARTHQUAKE-RESISTANT BLDGS. ONLY			ALL STEEL- & REINF.-CONC.-FRAME BLDGS.		
POINT ╳	NO. OF BLDGS.	FLOOR AREA	POINT ⊙	NO. OF BLDGS.	FLOOR AREA	POINT ●	NO. OF BLDGS.	FLOOR AREA
1	8	75.7	6	6	56.9	1	10	121.6
2	8	227.2	2	8	227.2	2	19	302.0
3	6	76.1	7	3	63.5	3	5	181.8
4	4	59.4	8	3	57.5	4	3	37.8
5	7	198.6	5	5	191.6	5	2	50.9
TOTAL	33	637.0	TOTAL	25	596.7	TOTAL	39	694.1

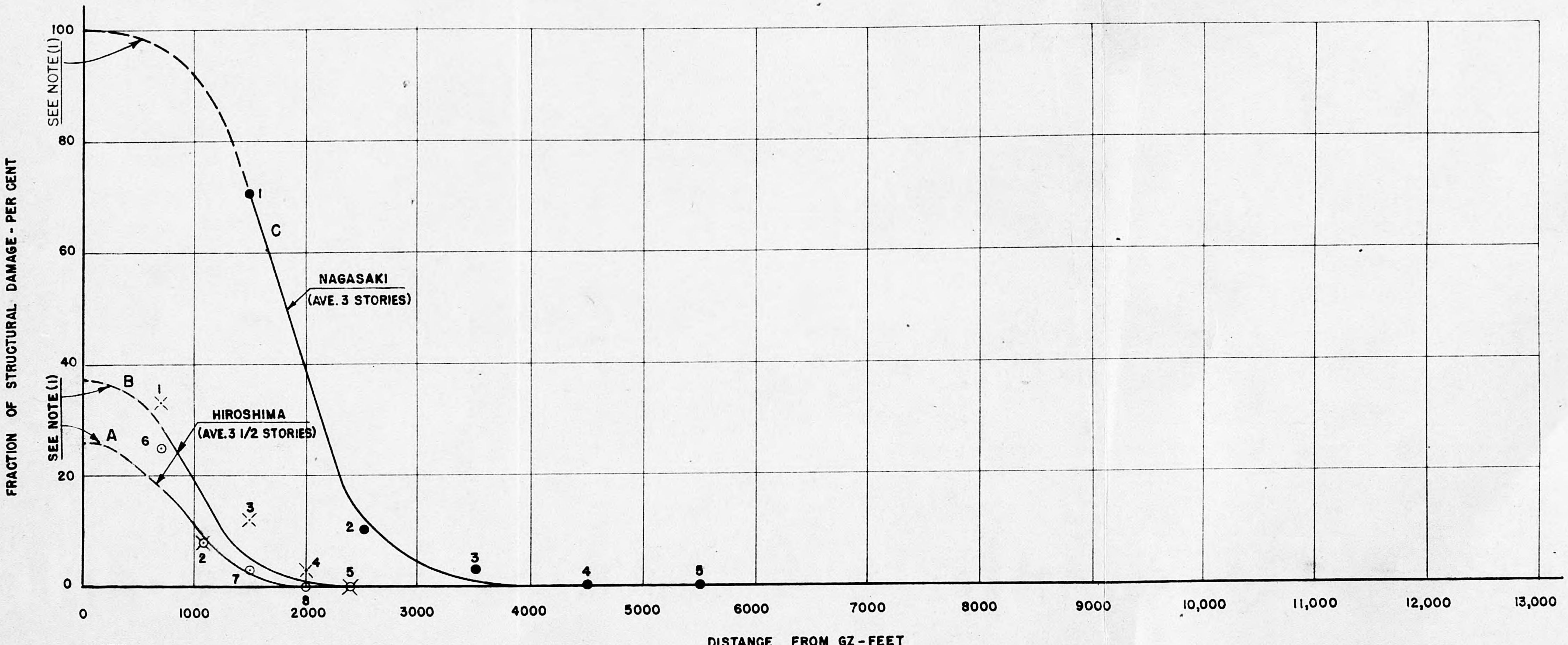
STRUCTURAL DAMAGE BY BLAST TO MULTISTORY STEEL- AND REINFORCED-CONCRETE-FRAME BUILDINGS

(BASED ON TOTAL FLOOR AREA)

HIROSHIMA, EARTHQUAKE-RESISTANT BLDGS. ONLY — MAE = 0.03 SQ. MI. (CURVE A)

HIROSHIMA, ALL STEEL- & REINF.-CONC.-FRAME BLDGS. — MAE = 0.05 SQ. MI. (CURVE B)

NAGASAKI, ALL STEEL- & REINF.-CONC.-FRAME BLDGS. — MAE = 0.43 SQ. MI. (CURVE C)



NOTE:

(1) CURVES DASHED WHERE EXTRAPOLATED BEYOND AVAILABLE DATA

(2) MAE'S WERE COMPUTED FROM THE CURVES BY ANNULAR RING METHOD

U.S. STRATEGIC BOMBING SURVEY

BUILDING DAMAGE

HIROSHIMA & NAGASAKI, JAPAN

FIGURE 33

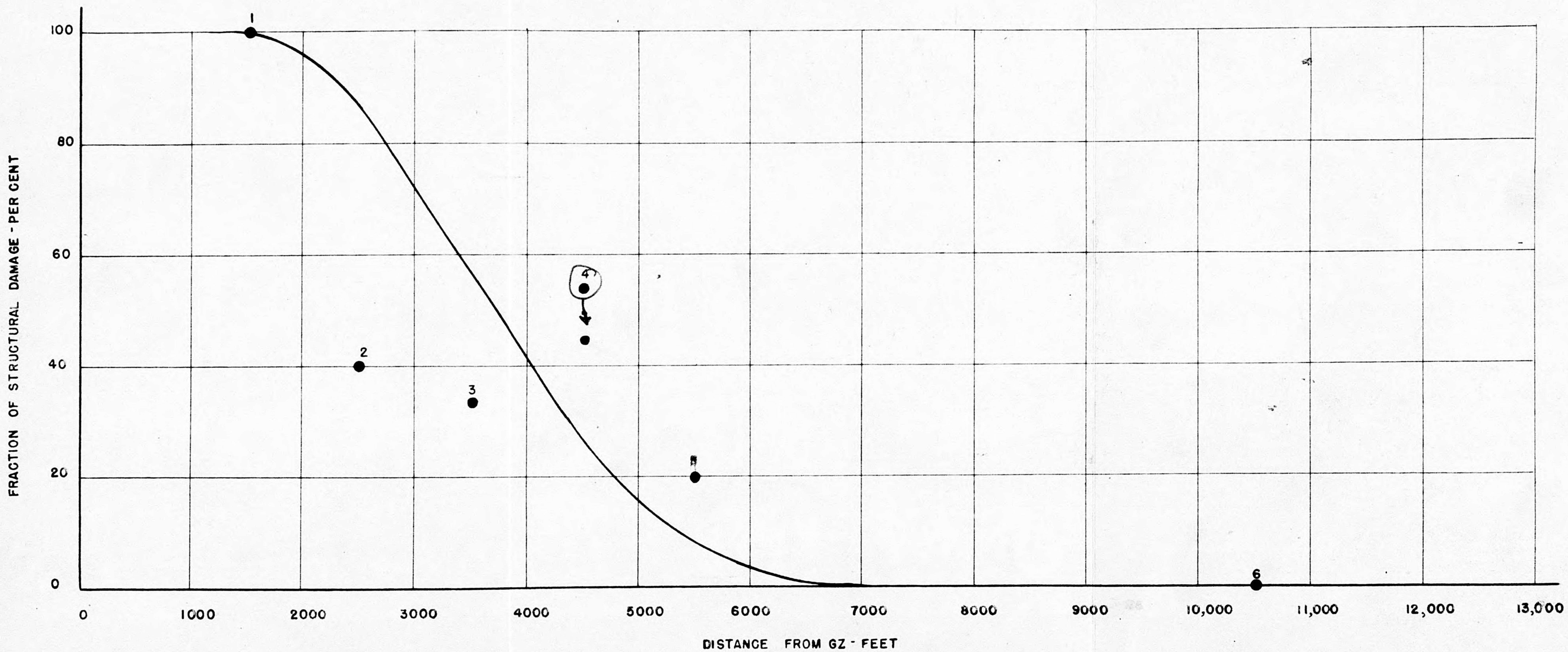
STRUCTURAL DAMAGE BY BLAST TO ONE-STORY HEAVY STEEL-FRAME BLDGS.

(BASED ON TOTAL FLOOR AREA)

NAGASAKI MAE = 1.8 SQ. MI.

(NO BLDGS. OF THIS TYPE IN HIROSHIMA)

NAGASAKI		
AREAS IN 1000'S OF SQ. FT.		
POINT	NO. OF BLDGS	FLOOR AREA
1	6	145.0
2	1	15.0
3	10	183.0
4	9	349.0 — 427
5	2	165.0
6	6	203.0
TOTAL	34	1060.0 — 1138



Drawing has been corrected

NOTE:

MAE WAS COMPUTED FROM THE CURVE BY ANNULAR RING METHOD.

SECRET

U.S. STRATEGIC BOMBING SURVEY
BUILDING DAMAGE
HIROSHIMA & NAGASAKI, JAPAN
FIGURE 234

SECRET

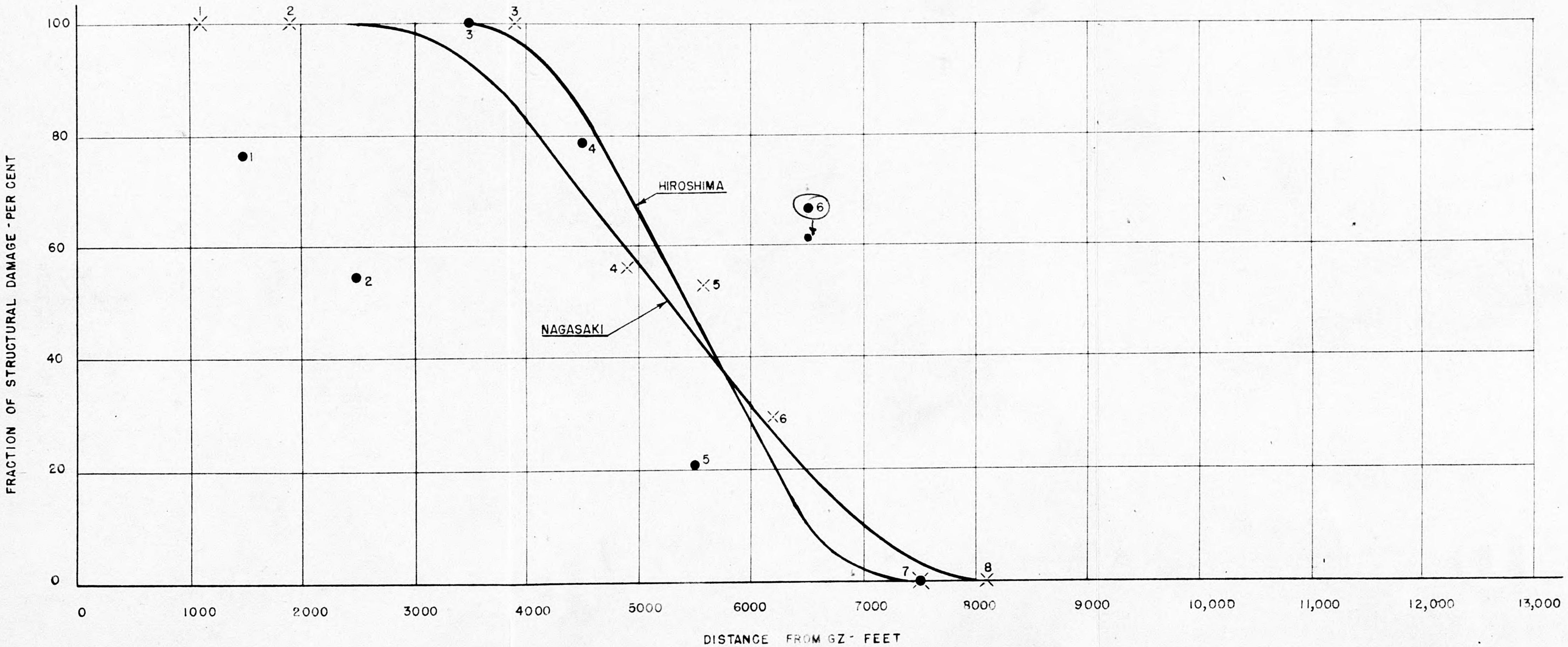
HIROSHIMA		AREAS IN 1000'S OF SQ.FT.		NAGASAKI	
POINT ✕	NO. OF BLDGS.	FLOOR AREA	POINT ●	NO. OF BLDGS.	FLOOR AREA
1	1	4.4	1	2	22.0
2	1	1.3	2	2	9.0
3	3	19.8	3	1	10.0
4	3	22.2	4	14	518.0
5	3	10.9	5	5	154.0
6	5	26.2	6	4	18.0
7	1	4.7	7	1	10.0
8	1	4.9			
TOTAL	18	94.4	TOTAL	29	741.0

STRUCTURAL DAMAGE BY BLAST TO ONE-STORY LIGHT STEEL-FRAME BLDGS.

(BASED ON TOTAL FLOOR AREA)

HIROSHIMA MAE = 3.4 SQ. MI.

NAGASAKI MAE = 3.3 SQ. MI.



NOTE:

MAE'S WERE COMPUTED FROM THE CURVES BY ANNULAR RING METHOD.

Drawing has been corrected

SECRET

U.S. STRATEGIC BOMBING SURVEY

BUILDING DAMAGE

HIROSHIMA & NAGASAKI, JAPAN

FIGURE 335

STRUCTURAL DAMAGE BY BLAST TO LOAD-BEARING BRICK-WALL BLDGS.

(BASED ON TOTAL FLOOR AREA)

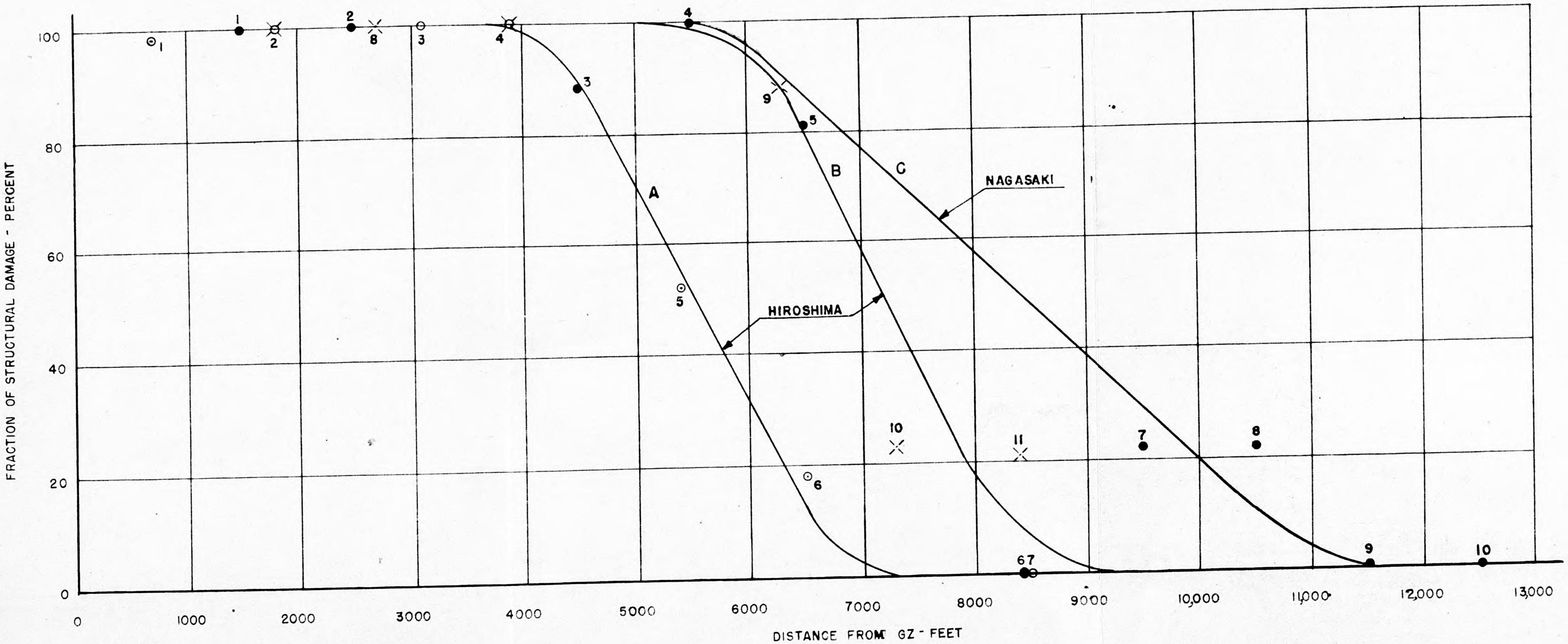
HIROSHIMA, MULTISTORY BLDGS. — MAE = 3.6 SQ.MI. (CURVE A)

HIROSHIMA, ONE-STORY BLDGS. — MAE = 6.0 SQ.MI. (CURVE B)

NAGASAKI, ONE-STORY BLDGS. — MAE = 8.1 SQ.MI. (CURVE C)

AREAS IN 1000'S OF SQ. FT.

HIROSHIMA						NAGASAKI		
MULTISTORY L.-B. BRICK			ONE-STORY L.-B. BRICK			ONE-STORY L.-B. BRICK		
POINT ⊙	NO. OF BLDGS.	FLOOR AREA	POINT ×	NO. OF BLDGS.	FLOOR AREA	POINT ●	NO. OF BLDGS.	FLOOR AREA
1	7	52.7	2	4	27.4	1	3	39.0
2	1	8.0	8	6	53.8	2	1	10.0
3	1	9.9	4	3	13.0	3	4	16.0
4	5	77.6	9	3	49.6	4	8	148.0
5	3	10.9	10	4	98.3	5	3	16.0
6	2	28.1	11	9	40.8	6	1	8.0
7	1	2.0				7	1	9.0
						8	5	90.0
						9	4	39.0
						10	4	15.0
TOTAL	20	189.2	TOTAL	29	282.9	TOTAL	34	390.0



NOTE:

MAE'S WERE COMPUTED FROM THE CURVES BY ANNULAR RING METHOD.

SECRET

U.S. STRATEGIC BOMBING SURVEY

BUILDING DAMAGE
HIROSHIMA & NAGASAKI, JAPAN
FIGURE 436

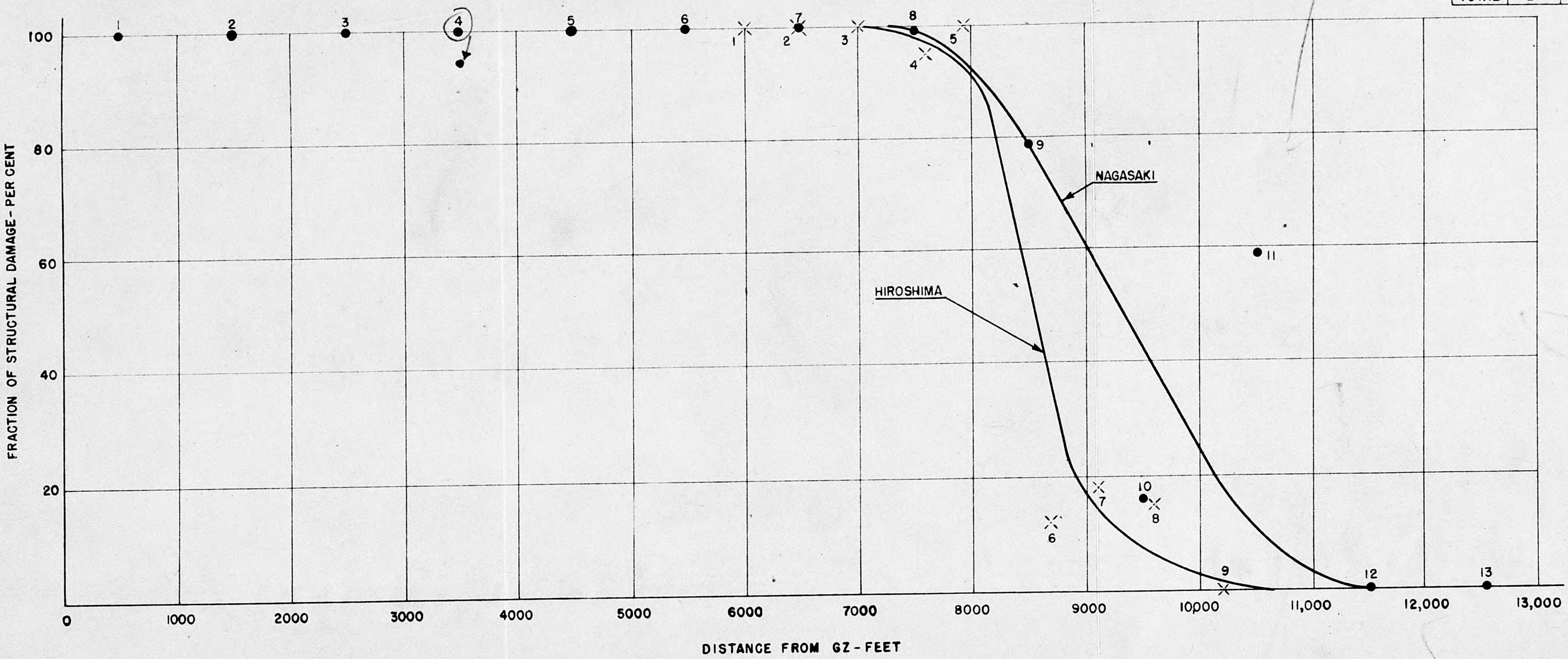
SECRET

HIROSHIMA		AREAS IN 1000'S OF SQ. FT.		NAGASAKI	
POINT ✕	NO. OF BLDGS.	FLOOR AREA	POINT ●	NO. OF BLDGS.	FLOOR AREA
1	1	3.2	1	11	25.0
2	3	7.5	2	95	259.0
3	1	4.2	3	27	82.0
4	3	61.4	4	22	213.0
5	1	38.4	5	43	154.0
6	3	29.3	6	18	178.0
7	8	118.7	7	13	96.0
8	5	111.6	8	4	10.0
9	2	149.0	9	21	92.0
			10	6	116.0
			11	12	54.0
			12	12	108.0
			13	1	7.0
TOTAL	27	523.3	TOTAL	285	1394.0

STRUCTURAL DAMAGE BY BLAST TO WOOD-FRAME INDUSTRIAL-COMMERCIAL BLDGS. OF DIMENSION TIMBER CONST.

(BASED ON TOTAL FLOOR AREA)

HIROSHIMA MAE = 8.5 SQ. MI.
NAGASAKI MAE = 9.9 SQ. MI.



NOTE:

MAE'S WERE COMPUTED FROM THE CURVES BY ANNULAR RING METHOD.

Drawing has been corrected

SECRET

U.S. STRATEGIC BOMBING SURVEY

BUILDING DAMAGE
HIROSHIMA & NAGASAKI, JAPAN
FIGURE 137

in both cities
~~in Hiroshima and up to 4 miles at Nagasaki.~~ In addition to the 30.7 per cent of the built-up area of Nagasaki which suffered structural damage there was an additional 9.3 per cent which was superficially damaged, roof stripping and disturbance of roof tile having been found as far as 19,000 feet from Ground Zero. Wall and roof stripping was found at Hiroshima up to 22,000 feet, and glass breakage was reported beyond 37,000 feet. There were instances in which corrugated-asbestos siding and roofs were stripped from steel-frame buildings without damage to the structural framework. There were other buildings where evidence indicated that the initial damage by blast was superficial, but subsequent fire had resulted in structural damage through warping and softening of steel supporting members. Cases of this nature, however, were relatively uncommon. Superficial damage, although not so important nor so spectacular as building collapse and heavy structural damage, extended the effectiveness of the bomb by exposing machinery, tools, and supplies to the elements, and by making more difficult the work of clearance and the restoration of necessary shelter for victims of the attacks. (Photos 166-167).

3. <u>Causes of Damage</u>. The structural damage to buildings in both cities was due to blast alone, blast and fire combined, and fire alone. Since the limits of structural blast damage to buildings extended beyond the burned-over areas, except for multi-story, steel- and reinforced-concrete-frame buildings, it is believed that in most cases buildings which suffered mixed damage were structurally damaged by the initial blast, and subsequent fires merely intensified the damage. Superficial

damage, for the most part, resulted from blast. There were wooden, tile, and some metal surfaces which were charred, scorched, or otherwise marked by flash burns, which might be classed as superficial damage, and a number of buildings affected by fires which caused superficial or interior damage but which were extinguished before structural or widespread damage resulted. At Nagasaki, the damage was due mostly to blast and blast plus fire. At Hiroshima, the structural damage to buildings studied was mainly due to blast. It was often possible in the latter city, on close inspection, to separate blast-damage areas from fire-damage areas. There was no evidence found of earth-shock damage to building.

a. <u>Blast</u>. The largest percentage of structural damage attributed to blast alone was almost 85 per cent, and occurred in the heavy and light, steel-frame buildings.

b. <u>Blast and Fire</u>. About 75 per cent of the structural damage in reinforced-concrete and load-bearing brick-wall buildings was due to blast plus fire. For single-story, light, steel-frame buildings, 20 per cent of the structural damage was due to blast plus fire.

c. <u>Fire</u>. Only in load-bearing brick-wall buildings and industrial and domestic wood-frame buildings was there structural damage caused by fire alone, and this was less than 10 per cent of the total structural damage for these building categories. Twenty-five per cent of the structural damage to multi-story, earthquake-resistant buildings was due to fire alone. For multi-story, steel- and reinforced-concrete frame buildings, both earthquake- and nonearthquake-resistant, 15 per cent of all structural damage was due to fire alone. Less than five per cent of the structural damage to the multi-story, load-bearing brick-wall class was attributed to fire alone (Table 38). ← Insert Table 38

TABLE 38

STRUCTURAL DAMAGE BY FIRE ALONE

Building Type	Percentage of Total
Single-story, load-bearing, brick wall Industrial and domestic wood-frame	- 10
Multi-story, load-bearing, brick-wall	- 5
Multi-story, steel- and reinforced-concrete frame, both earthquake- and nonearthquake-resistant	15
Multi-story, earthquake-resistant	25

the pressure was principally in a horizontal direction and the major portion of the damage occurred to walls facing the blast. Blast damage in Hiroshima spread almost uniformly in all directions from Ground Zero, resulting in an approximately circular area of devastation. The area of damage at Nagasaki was not so regular nor so evenly spread. Because of the topographical formation at this city, the force of the blast was confined principally to the valley, resulting in a comparatively long, narrow, irregular area of destruction, the fringe of which frame buildings, both earthquake- and nonearthquake-resistant, 15 per cent of all structural damage was due to fire alone. Less than five per cent of the structural damage to [the] multi-story, load-bearing brick-wall class was attributed to fire alone (Table 38). ← Insert Table 38

4. Characteristics of Damage

a. Blast. The atomic-bomb detonations were characterized by far-reaching, crushing blast effects, ~~The blast effects produced~~ [which] were uniform and essentially those of a conventional high-explosive weapon, although on a much larger scale. Instead of producing localized effects, entire buildings were crushed or distorted as units over a wide area. The effect of the atomic bomb on buildings was usually that of a powerful push which shoved them over or left them leaning. Buildings near Ground Zero, where the blast pressure was almost vertically downward, were crushed or, in some instances, had their roofs blown in with relatively little damage to walls. At greater distances, they were exposed to both vertical and horizontal forces, thereby suffering damage both to roofs and walls facing the blast. At considerable distances, the pressure was principally in a horizontal direction and the major portion of the damage occurred to walls facing the blast. Blast damage in Hiroshima spread almost uniformly in all directions from Ground Zero, resulting in an approximately circular area of devastation. The area of damage at Nagasaki was not so regular nor so evenly spread. Because of the topographical formation at this city, the force of the blast was confined principally to the valley, resulting in a comparatively long, narrow, irregular area of destruction, the fringe of which was at greatly varying distances from Ground Zero. The blast effects were most striking at Nagasaki, where the sides of concrete buildings facing the detonation were stove in as if wooden boxes. The skeletons of long lines of steel-frame factory sheds, over a mile from Ground Zero, leaned away from the explosion. Strongly-built steel members were bent and twisted, and roofs of reinforced-concrete buildings were crumpled and collapsed. At Hiroshima, although similarly characteristic damage was experienced, the more strongly-built reinforced-concrete structures of that city were damaged only relatively near the point of detonation, and beyond that area their burned-out, but otherwise undamaged, structural frames stood amidst the twisted steel and rubble which marked the locations of former brick and steel-frame buildings.

(1) Negative Phase. The negative phase of the atomic-bomb detonation, at which time below-atmospheric pressures existed, occurred during the period immediately following the passing of the initial, positive blast wave and resulted in characteristic damage such as glass and window shutters, and occasionally plaster wall covering, being blown out toward the blast. Damage of this nature, however, was relatively uncommon and all significant damage to buildings occurred during the positive phase when the pressure was greater than atmospheric.

(2) Shielding. Some buildings were shielded from the direct effects of the bomb blast by others, and

therefore suffered less damage than comparable structures at the same distance from Ground Zero. At points near Ground Zero there was little or no shielding because of the height of the buildings, which was limited to 100 feet by the Japanese building code, and the height of detonation of the bombs. Shielding played a more important role in Nagasaki where hills divided the city, and, as a result, more than one-half the residential units escaped serious damage.

(3) Reflection and Diffraction. Reflection and diffraction effects were observed in both Hiroshima and Nagasaki. Diffraction was evidenced by damage in locations where shielding should have afforded some degree of protection, had the blast wave travelled in a straight line. It is considered that this phenomenon was responsible for a considerably increased proportion of damage in both cities. There was evidence of reflection of blast in the damage to parapet walls on the side away from the bomb, while parapet walls facing the detonation remained undamaged. In these cases it appeared likely that the blast wave reflected from the roof surface reinforced the blast impinging directly upon the wall.

b. Fire. Widespread fire damage may also be described as a characteristic result of the atomic bomb explosions. Fires were ignited by the radiant heat of the atomic-bomb detonation within a radius of 3,000 feet from Ground Zero at Nagasaki, and up to 4,000 feet at Hiroshima. The majority of these fires started in dwellings and other buildings of combustible construction or containing combustible material, and in the debris created by the blast. Other fires which reached major proportions were started over wide areas in both cities by secondary causes, or as an indirect result of the bomb's blast, such as debris knocking over or falling on open-flame devices and ignition of combustible building material or debris by electrical short circuits. Fire damage effects were more intense and greater in proportion to other types of damage in Hiroshima than in Nagasaki. The causes and extent of fire damage are discussed in detail in another section of this chapter.

F. DAMAGE TO MACHINE TOOLS

1. Extent of Damage. The major industrial plants in Hiroshima were located about one and a half miles from the center of the city, and the machine tools in them were not damaged. Numerous small engineering shops, however, were located within the area affected by the bomb and virtually all machine tools in these buildings within 3,500 feet of Ground Zero were heavily damaged. These shops represented only one-quarter of the city's total industrial production. At Nagasaki no damage to machines and equipment was recorded outside a radius of 6,500 feet from Ground Zero. Damage up to 6,000 feet varied between 5 and 10 per cent of the total, except in wood-frame buildings where the damage was 95 per cent. A total of 26 per cent of all machine tools in the industrial plants affected by the atomic bomb was damaged. Damage to

auxiliary equipment and plant utilities amounted to 45 per cent, as these installations were of lighter construction and presented larger surface areas to the blast. Damage to machine and building contents, as in the case of other types of weapons, was less than damage to the buildings. The extent and kind of damage to machinery depended almost entirely on the construction of, and the degree of damage sustained by, the buildings in which they were contained. (Photos 168-172).

a. Reinforced-Concrete Buildings. No reinforced-concrete buildings in Nagasaki were structurally damaged or had their contents damaged beyond 4,700 feet from Ground Zero. Within that distance, however, 86 per cent of the machine tools sustained some damage. Damage to small tools amounted to 45 per cent. Raw materials and semi-finished products sustained 10 per cent damage. There were no reinforced-concrete shop buildings in Hiroshima.

b. Steel-Frame Buildings. The maximum range for damage to industrial steel-frame structures in Nagasaki was 5,600 feet. In those buildings 21 per cent of the machines and 36 per cent of the equipment sustained damage of varying degrees. Small tools sustained damage amounting to 65 per cent. A relatively small number of tools was damaged in buildings of similar construction in Hiroshima, although 42 per cent of the total floor area was structurally damaged. This may be explained by the fact that the blast caused mass distortion of the steel frame without tearing loose heavy structural members, and wall and roof sheathing debris was light. The major portion of machine damage occurred in buildings which burned.

c. Brick Buildings. At Hiroshima, 28 per cent of the machine tools housed in load-bearing brick-wall buildings were damaged. All machine tools in one building which was burned out were heavily damaged. There were no machine tools in this type of building in Nagasaki.

d. Wood-Frame Buildings. Only 3 per cent of the machine tools in wood-frame buildings damaged by blast were heavily damaged at Hiroshima. All machine tools in buildings which burned were seriously damaged. At Nagasaki, 95 per cent of the machine tools in this type of structure suffered damage. These buildings, however, were utilized only as temporary auxiliary machine shops for industrial plants and their importance from an industrial standpoint was relatively small.

2. Causes of Damage. The principal causes of damage to machine tools and building contents were fire, debris, and weather exposure. Because of the differences between Hiroshima and Nagasaki in the housing of machines, the locations of their industrial plants in relation to the points of detonation, and the fact that a larger area of Hiroshima was affected by fire, the causes of damage to machine tools and equipment varied considerably in the two cities in buildings of comparable types.

a. Reinforced-Concrete Buildings. ~~There were~~ Machine tools were housed in buildings of this type in Nagasaki only. Debris, in the form of collapsed parts of the buildings, was the major instrument of damage in this type of structure and accounted for 80 per cent of the total damage to machine tools; fire accounted for 9 per cent; and weathering effects, 11 per cent.

b. Steel-Frame Buildings. Blast, debris, and lateral movement of structures caused 70 per cent of the machine-tool damage at Nagasaki; 27 per cent of the damage was ascribed to weathering effects; and fire accounted for only 3 per cent. At Hiroshima, moderate initial damage to machine tools in buildings of this type resulted from blast, but in the burned-over section of the city, there was almost total damage to machinery by fire. In buildings outside the fire area there was some exposure damage.

c. Brick-Wall Buildings. Machine tools were found in this type of structure only in Hiroshima. Debris caused serious damage to only 5 per cent of the machine tools in these buildings although 30 per cent of the total floor area was structurally damaged. In those buildings which burned because of the combustibility of building material and contents, 23 per cent of the machine tools were seriously damaged by fire.

d. Wood-Frame Buildings. At Nagasaki 54 per cent of the machine-tool damage in wood-frame buildings was due to exposure to the elements. Fire damage accounted for only 10 per cent of the damage, and debris and mass movement of the structures accounted for 26 per cent. The most serious damage to heavy machines was the overturning and fracturing of machine castings. Blast and a combination of blast, fire, and debris accounted for 10 per cent of the machines. In Hiroshima, debris caused total or heavy damage to only 3 per cent of the machine tools in these buildings, although 64 per cent of the total floor area was structurally damaged by blast. Serious damage resulting from debris

Photo 168. Nagasaki. Mitsubishi Boys Industrial School. Wood-frame building used for industrial purposes totally damaged by blast and fire. Machine tools totally or heavily damaged by blast, debris, and fire.

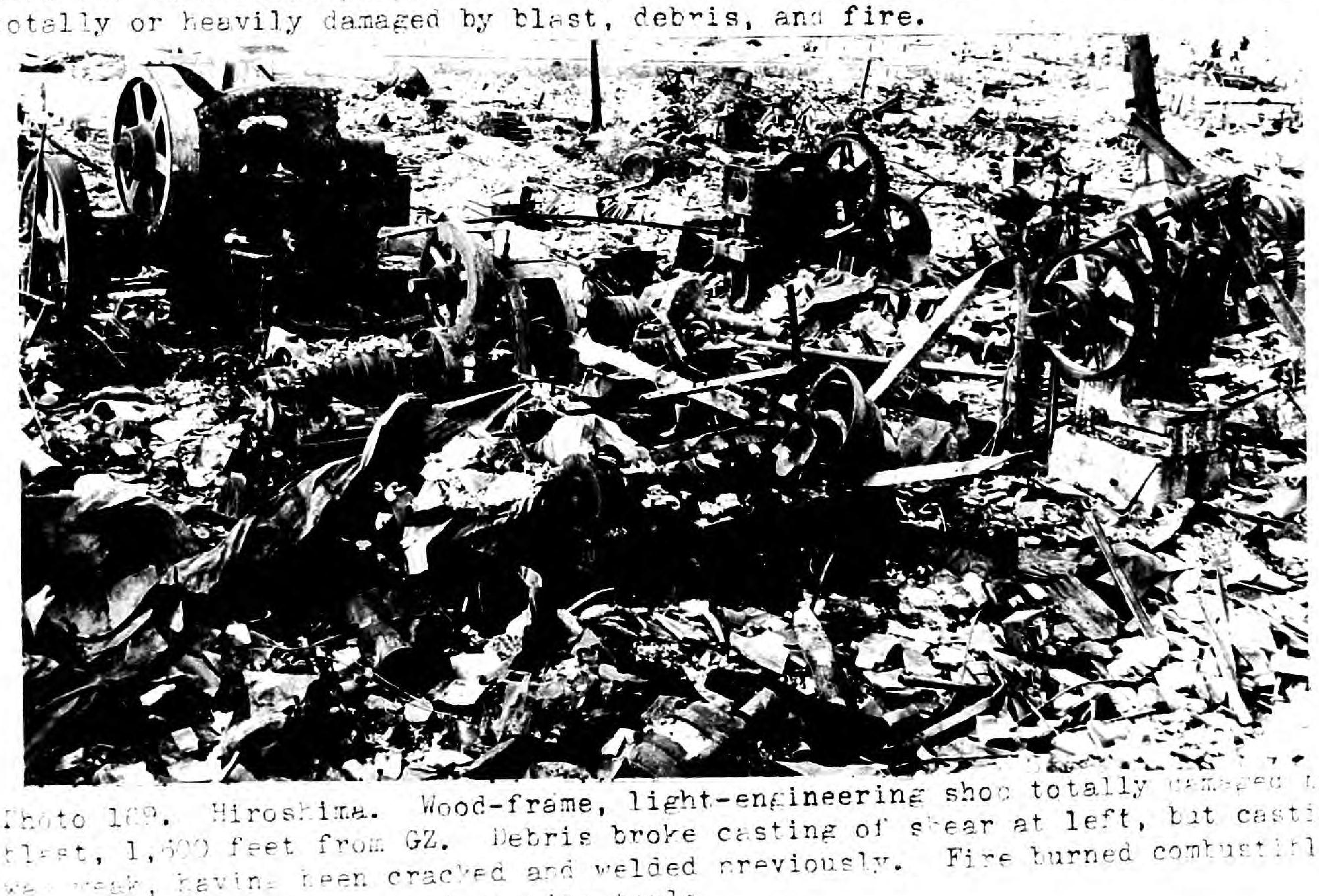


Photo 169. Hiroshima. Wood-frame, light-engineering shop totally damaged by blast, 1,[illegible]00 feet from GZ. Debris broke casting of shear at left, but casting was weak, having been cracked and welded previously. Fire burned combustible debris and heavily damaged machine tools.

Photo 170. Nagasaki. Mitsubishi Steel and Arms Plant. Steel-frame building damaged by blast and machines totally damaged by collapse of reinforced-concrete roof.

Photo 171. Nagasaki. Mitsubishi Boys Industrial School. Wood-frame building totally damaged by blast, but vertical millers still standing.

Photo 172. Nagasaki. Same as Photo 171. Wood-frame buildings totally damaged by blast and machine tools totally damaged by debris and fire.

was caused only by falling overhead shafts and pulleys. Mass movement of buildings caused some damage, but the major portion of damage was due to fire which burned buildings and their contents.

G. DAMAGE TO BRIDGES

1. Types and Construction of Bridges

a. Hiroshima. There were 81 important bridges scattered over the entire city of Hiroshima, ranging from 260 to 15,600 feet from Ground Zero. These served not only for local transportation needs but also as overcrossings for the city's services and utilities. Of those studied, the 39 highway bridges, comprising 14 timber, 15 concrete, and 10 of steel construction were most numerous as a class. There were nine street railway bridges, most of which were in the heart of the city, consisting of two timber, one reinforced-concrete, and six steel bridges. The six railroad bridges, of strongly-built, steel construction, were, as a class, most distant from Ground Zero. There were four pedestrian bridges of timber, and seven bridges (4 timber and 3 steel) which served as aqueducts and overcrossings for utilities. The bridges in general were designed to carry lower loadings than comparable structures in the United States. The design, construction, and materials appeared to be inferior to United States standards, except for the steel-plate-girder bridges and steel-truss aqueducts.

b. Nagasaki. The 35 bridges studied at Nagasaki, all within 7,650 feet of Ground Zero, were used to span either the main body of the Urakami River or its tributaries. They were of relatively short span as nowhere did the width of the river exceed 240 feet. The maximum length of a single span was 120 feet. There were 16 reinforced-concrete bridges of the T-beam type; three curved-chord, steel-truss bridges; two of stone-arch construction; one reinforced-concrete arch; six plate-girder bridges; two timber bridges; one of wood-and-concrete construction; one of wood-and-steel construction; and three bridges of reinforced concrete and structural steel. These bridges covered a wide variety of types but none was outstanding or original in design.

2. Extent and Causes of Damage. Of the 35 bridges in Nagasaki, at distances varying from 300 to 7,650 feet from Ground Zero, four were totally or heavily damaged by blast or fire and six others sustained some degree of structural damage. At Hiroshima, 17 bridges were totally or heavily damaged, and 10 others suffered degrees of damage ranging from displaced and distorted decks and minor structural members to broken railings, curbs, posts, and copings. In terms of deck area, 33 per cent of the 19 timber bridges and four per cent of the 23 steel bridges were totally damaged by blast and fire. None of the 15 concrete bridges suffered total damage. Proximity to Ground Zero did not seem to affect seriously the heavily-built concrete bridges, possibly because of the mass of the bridges and the vertical action of the blast in the direction of their greatest strength, the design of bridges being such as to resist heavy vertical loads. Bridges of less mass but farther from Ground Zero were damaged by displacement which resulted in distortion and failure of members. Plate-girder bridges do not possess large mass, and offered relatively greater surfaces to the blast. Wood bridges were particularly vulnerable to the atomic bomb, sustaining total damage by

fire and blast in Nagasaki up to 5,760 feet from Ground Zero, and in Hiroshima, up to 4,670 feet from Ground Zero. Steel railroad bridges in Hiroshima, being most distant from Ground Zero (5,580 to 8,480 feet), completely escaped damage except for radiant heat effects which to a minor degree on five bridges discolored the paint on girders facing Air Zero.

a. Blast. At Nagasaki two steel-plate-girder railroad bridges, one 840 and the other 900 feet from Ground Zero, were displaced and suffered heavy structural damage as a result of blast. One timber bridge was totally demolished by blast, 5,760 feet from Ground Zero. Two bridges, one of steel and concrete, the other concrete, 1,950 and 2,330 feet from Ground Zero, respectively, had spans blown off their supports. In addition, the decks of the remaining spans of the steel-and-concrete bridge were blown 150 feet away. Four concrete bridges from 300 to 1,710 feet from Ground Zero sustained lateral displacement from one to eight inches as a result of blast. Blast damage to six other concrete bridges at Nagasaki at distances from 750 to 3,750 feet from Ground Zero ranged from displacement of deck and spalling of concrete girders to demolished railings. At Hiroshima, two steel, street-railway bridges, 1,000 and 4,670 feet, respectively, from Ground Zero, were heavily damaged by blast. One steel highway bridge, 1,190 feet from Ground Zero, was totally collapsed. Five concrete (4,270 to 6,450 feet from GZ) and five steel highway bridges (260 to 7,600 feet from GZ) were damaged in extent ranging from distorted decks to superficial damage, such as blown-off railings and trim (Photo 173). Flood and typhoon were credited with

Photo 173. Hiroshima. Intersection of two bridges, approximately 930 feet from GZ. All damage caused by blast.

damaging 9 timber, 7 concrete, and 3 steel bridges at Hiroshima between 17 September and 5 October 1945. It is considered probable that blast loadings from the atomic bomb had weakened some of these bridges and left them in a vulnerable condition.

b. Fire. At Hiroshima ~~five~~ 5 timber highway bridges were structurally damaged by fire. One timber pedestrian bridge, 4,760 feet from Ground Zero, was completely consumed by fires which spread from adjacent areas. No bridges at Nagasaki were structurally damaged by fire alone, but superficial damage in the form of burned ties was sustained by a steel railroad bridge 1,650 feet from Ground Zero ~~at Nagasaki~~.

c. Blast and Fire. One timber bridge in Nagasaki, 5,460 feet from Ground Zero, was completely demolished by blast and fire. At Hiroshima, one timber street railway bridge, 4,670 feet from Ground Zero, was totally damaged. In addition, one steel and four timber bridges, used as aqueducts and overcrossings at Hiroshima, totally collapsed as a result of blast and fire, and two other steel bridges were structurally damaged. These seven bridges carried water mains, telephone wires, and low- and high-pressure gas mains.

H. DAMAGE TO STACKS

1. Types of Stacks. Stacks in both Hiroshima and Nagasaki were for the most part of reinforced-concrete, brick, or steel construction. Reinforced-concrete stacks were the most numerous; those of brick construction were second; and steel stacks were in the minority. The average height of all stacks was less than 70 feet. There were few over 100 feet, the highest in Hiroshima being 120 feet. Several other

types were in use, such as vitrified-tile and asbestos-pipe, but these were not considered worthy of study.

a. Reinforced-Concrete Stacks. Concrete stacks were generally well designed and were sufficiently strong to withstand heavy wind loads, as well as the effects of earth tremors. Mediocre quality of workmanship, however, was reflected in the lack of care in placing reinforcing steel and in the varying thickness of concrete. One-course brick lining was used in many concrete stacks, usually to a height of 10 to 15 feet.

b. Brick Stacks. Stacks of brick construction, especially those of octagon shape, were usually well designed and well built. Materials and workmanship were good. The smaller, square-shaped brick stacks, however, were generally built too light and many required bracing with angle iron or steel straps.

c. Steel Stacks. Stacks of this type, comprising the smallest number of all types observed, followed no apparent design standards. Sections of some were lap welded; others had riveted joints. The chief weakness of this type of stack lay in methods of anchorage, which were usually ineffective in safeguarding against overturning. The advantages in the use of these stacks were the economy and ease of construction and the fact that, even when knocked down, they could be quickly repaired on the ground and re-erected by crane in one piece.

2. Cause and Extent of Damage. It was considered that all damage sustained by stacks resulted from blast effects of the atomic bomb inasmuch as there was no evidence, such as spalled concrete, vitrified

Photo 174. Hiroshima. Reinforced-concrete stack, 1,100 feet from GZ, 60 feet high, 4 feet in diameter, sheared off at 12 feet.

brick, or oxidized steel, to indicate any portion of the damage was caused by fire. In both cities there were numerous apparently undamaged stacks left standing although the buildings they served had been reduced to wreckage. At Hiroshima, within a radius of 8,700 feet from Ground Zero, 15 per cent of the concrete, (Photo 174) 50 per cent of the brick, and 70 per cent of the steel stacks were damaged to such an extent as to render them unusable without almost complete rebuilding. At Nagasaki, only four out of approximately 30 concrete stacks were damaged within 6,000 feet of Ground Zero. Two of these stacks, moreover, had been very close to high-explosive bomb hits during an attack prior to the atomic bomb explosion and it was possible that this circumstance might have contributed to the failure of the stacks. All brick and steel stacks within the same area were totally or heavily damaged. Stacks of reinforced-concrete construction proved most resistant to blast; brick was highly vulnerable; and steel stacks were the most easily damaged. The mean areas of effectiveness of the atomic bomb against reinforced-concrete, brick, or steel stacks at Hiroshima were computed to be 0.3, 2.7, and 4.1 square miles, respectively; the mean effective radii being 1,625 feet, 4,900 feet, and 6,050 feet. In view of the similarity of design and construction of stacks in the two cities, these figures should be applicable in no lesser degree to the stacks in Nagasaki. The amount of damage to concrete stacks in both Nagasaki and Hiroshima was almost negligible compared to the amount of damage to buildings within the same areas. The resistance of concrete stacks to blast effects of the atomic bomb might be attributed to a number of factors, such as structural flexibility, minimum exposed surface, fire-resistive qualities, vertical angle of blast, and, in some instances, part shielding by intervening buildings.

I. Damage to PUBLIC UTILITIES

1. General. All public services and utilities in both Hiroshima and Nagasaki sustained damage as a result of the atomic bomb attacks, and were disrupted in whole or in part for varying lengths of time. As both cities were virtually paralyzed by the sudden, widespread, destructive effects of the detonations, the demand for services fell off as sharply as the supply. Despite the extent of damage and the chaotic conditions prevailing immediately following the attacks, some of the more vital services such as street railway, railroad, water, and electricity were restored to minimum levels within periods ranging from 24 to 72 hours in an effort to facilitate emergency rescue and clearance and to provide some measure of relief for the stricken populations.

2. Transportation

a. Street-Railway and Bus Service. Hiroshima depended almost entirely upon the street-railway system and busses for passenger transportation within the city and to outlying districts, since it contained only a small number of private vehicles. Nagasaki, having no busses, dpended heavily on its street-railway system for intra-urban transportation. Its double-track system carried a daily load of 77,000 passengers.

(1) Of the 123 street railway cars in Hiroshima, 20 per cent were damaged by fire and 45 per cent by blast. (Photos 125-126)

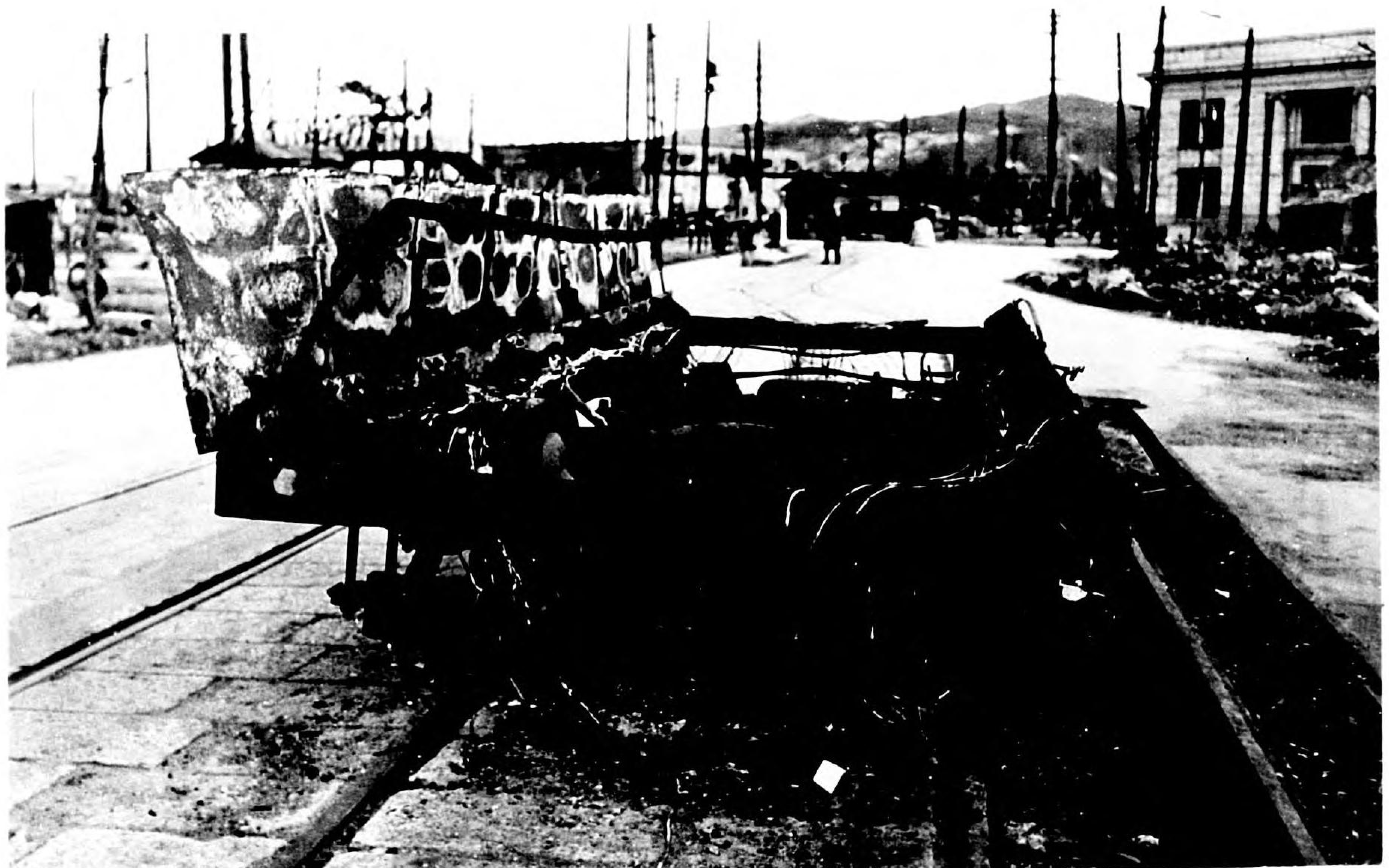


Photo 175. Hiroshima. Damaged street-railway car, 4,000 feet from GZ.

Photo 176. Hiroshima. Damaged car at [illegible] feet from GZ.

Fire damaged 21 per cent and blast 26 per cent of the motor busses. Both cars and busses were ignited by radiant heat within 1,500 feet of Ground Zero. Damage varying from total to slight was sustained by cars up to 12,500 feet from Ground Zero. Busses were damaged up to 5,500 feet from Ground Zero. In addition to the loss of rolling stock, there was a total of 11.4 miles of the overhead transmission system damaged by blast and fire. This damage included wood and steel poles and transmission cable, from 4,500 to 8,000 feet from Ground Zero. There was no damage to trackage except what was carried by bridges. Disruption of the entire electrical system resulted from fire and blast damage to converter stations as far as 6,400 feet from Ground Zero.

(2) The bomb which detonated over Nagasaki resulted in damage, both by fire and blast, to 70 per cent of that city's street-railway cars within 10,000 feet of Ground Zero, and five per cent of the total trackage. The system was further crippled by damage to 50 per cent of the trolley wire, electric power lines, and sheared and overturned steel power-line supports. It was estimated that 200,000 man hours would be required to repair Nagasaki's street-railway system.

b. Railroad

(1) Hiroshima's inter-city transportation was provided by the government railroad system, comprising the double-track Sanyo Main Line, together with classification yards, repair facilities, transit sheds and stations, and a single-track line, with intermediate stations within the city, to the deep-water harbor at Ujina. The average passenger rate per month was 1,824,960 persons; average freight tonnage amounted to 9,300 tons.

(2) Railroad facilities at Nagasaki consisted of a single-track line within the city, connecting it with Tosu Junction. There were three secondary stations within the city and the main Nagasaki Station at which the line terminated. The system served primarily as transportation for passengers within the urban area and to the surburban sections.

(3) Railroad stations in both cities suffered either total or heavy structural damage from blast and fire within 7,000 feet of Ground Zero. Classification and repair facilities at Hiroshima between 8,000 and 10,000 feet from Ground Zero were superficially damaged. All communications and signal systems were either heavily damaged, or rendered inoperative because of damage to communications buildings. Rolling stock was more

heavily damaged at Hiroshima, where 13 per cent of the freight cars, 93 per cent of the passenger cars, and 75 per cent of the electric cars were damaged by blast and fire up to 6,800 feet from Ground Zero. Rolling stock at Nagasaki sustained comparatively slight damage caused primarily by blast. More important track damage occurred at Nagasaki, where crossties, ignited by flaming debris, burned intermittently for distances of 10,000 to 15,000 feet, and buckled the steel rails. Further rail damage resulted through the displacement by blast of three bridges. Emergency repair work, however, permitted resumption of limited traffic after 48 hours. Although no damage was sustained by trackage or bridge crossings in Hiroshima, adjacent fires and blast debris on the tracks prevented utilization of some sections for a period of several days.

3. Wire Communications. The telephone and telegraph facilities of Hiroshima and Nagasaki sustained widespread damage as a result of the atomic bombings. One of the most serious consequences of the crippling of these utilities was the ensuing delay in organizing emergency relief and adequate rescue work in the two cities. The overhead wires and cables of the transmission systems, as a result of their exposed positions, were the hardest hit. At Hiroshima approximately 80 per cent of the overhead system was damaged by fire and blast. The damaged portion

of the system comprised over 27 miles of cable and approximately 92 per cent of a total of 7,451 wood poles carrying overhead lines. Poles were damaged by blast at 4,500 feet from Ground Zero, and burned at 6,500 feet; cable was stripped from hangers at 8,000 feet. At Nagasaki approximately 50 per cent, or 57 miles, of the aerial cables and open wires of the telephone system were heavily damaged, and 15 per cent, or 19 miles, of the open wires of the telegraph system sustained damage in varying degrees. The two exchange buildings at Hiroshima, one 2,000 feet (Photos 177-178) and the other 3,300 feet from Ground Zero, were damaged, and 100 per cent and 50 per cent, respectively, of the equipment contained in these buildings sustained total damage by fires resulting from short circuits. Nagasaki lost 60 per cent of its 4,891 subscribers' telephone sets as a result of the attack. The subsurface systems, comprising underground transmission cables, being the least exposed to the effects of fire and blast, suffered the smallest amount of damage. Cables and conduits were vulnerable, however, at bridge crossings and at exit points to the overhead system. Damage at these locations, although limited in extent, was sufficient to put approximately 80 per cent of Hiroshima's subsurface system out of service. Within nine days, 35 pairs of subsurface cable had been returned to service, being restricted entirely to prefectural and military needs. At Nagasaki, 10.8 per cent, or approximately 16 miles, of the underground cable system was heavily damaged. As a result of the bomb effects at Nagasaki, wire communications were partly paralyzed for a week.

Photo 177. Hiroshima. Bureau of Telephones Central District exchange building. Damage to equipment in reinforced-concrete building 2,000 feet from GZ.

Photo 178. Same as Photo 177.

4. Electric Power

a. Power Supply. Hiroshima was furnished electric power by the hydroelectric plants of the Nippon Electric Company through two substations and by a steam-electric plant of the Chugoku Electric Company through seven substations. Power was transmitted by overhead lines from the hydroelectric plants to the substations at 110 kv; from the steam plant at 55 kv. The substations of the Chugoku Company transformed from 22 kv to 3.3 kv for consumer distribution, except for several large industries and the street railway company which received power at 22 kv and transformed it to their own requirements. The 22-kv distribution was transmitted by both overhead and subsurface systems. Daily power consumption in Hiroshima was 80,000 kw for lighting and 170,000 kw for heating and motor energy. The electric supply system at Nagasaki, within the area affected by the atomic bomb, comprised eight transformer stations, two switch stations, and one small generating plant. The capacity of the power transformers was 86,500 kw which supplied 40,842 residential and 949 industrial consumers prior to the attack. The majority of their transmission lines was carried on steel towers and concrete standards.

b. Damage. At Hiroshima 70 per cent of the 3.3-kv overhead and feeder system was damaged by fire and blast. Of a total of 7,000 poles in use, 4,000 wood and 27 steel-lattice poles were damaged by blast and fire, and wires were blown from the poles by blast as far as 8,000 feet from Ground Zero. Concrete poles were not damaged. Of the remaining undamaged 30 per cent of the system, only 90 per cent was usable as some sections beyond the damaged area could not be supplied with electricity due to lack of connections to substations. No damage was sustained by the 22-kv subsurface system. In Nagasaki 32.4 per cent of the 66-kv open transmission lines sustained total damage. Of 76 steel towers, eight were totally damaged, and four concrete standards of a total of 30 were demolished. In addition, heavy damage was inflicted upon Nagasaki's distribution system which suffered the loss of 27.7 per cent of a total of approximately 134 miles of feeder lines; 24 per cent, or 1,491, of a total of 6,107 poles; and 27.6 per cent, or 483, of a total of 1,750 transformers. Damage to transformer substations and heavy equipment, although severe, was relatively light compared to that sustained by the overhead transmission and distribution systems. One substation at Hiroshima was heavily damaged by blast and fire 2,400 feet from Ground Zero, and another substation and a steam-electric plant, 7,700 feet from Ground Zero, were heavily damaged by fire which spread from adjacent areas. As a result of the damage to these two substations it was necessary to distribute the areas they served among the remaining substations. Four substations were slightly damaged at 5,500 feet and beyond; three substations were undamaged. At Nagasaki, three of a total of eight transformer stations sustained heavy damage to bus structures, insulators, and steel racks. Primary heavy equipment was only slightly damaged at these stations, (Photos 179-182).

5. Gas Supply System. Storage facilities of the gas supply system in both cities, consisting of large gas holders, were the most vulnerable to the blast effects of the atomic bomb. The two gas holders

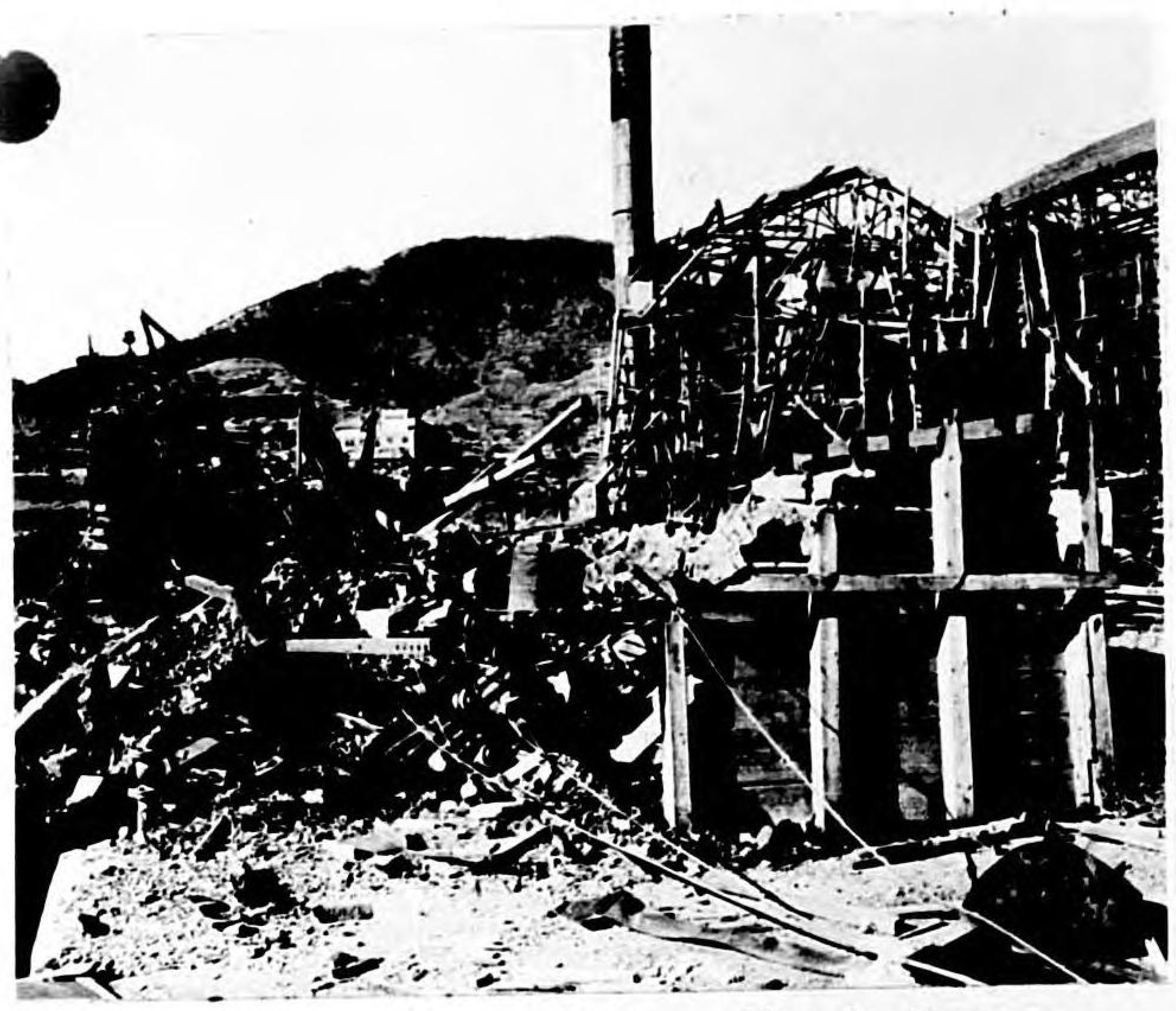


Photo 179. Nagasaki. Wood-frame building housing substation, 5,800 feet from GZ, 100 per cent structurally damaged by blast.

Photo 180. Nagasaki. Takenokubo substation, 3,600 feet from GZ. Unusually heavy concrete and steel construction withstood blast well.

Photo 181. Same as Photo 180. Interior of switch room.

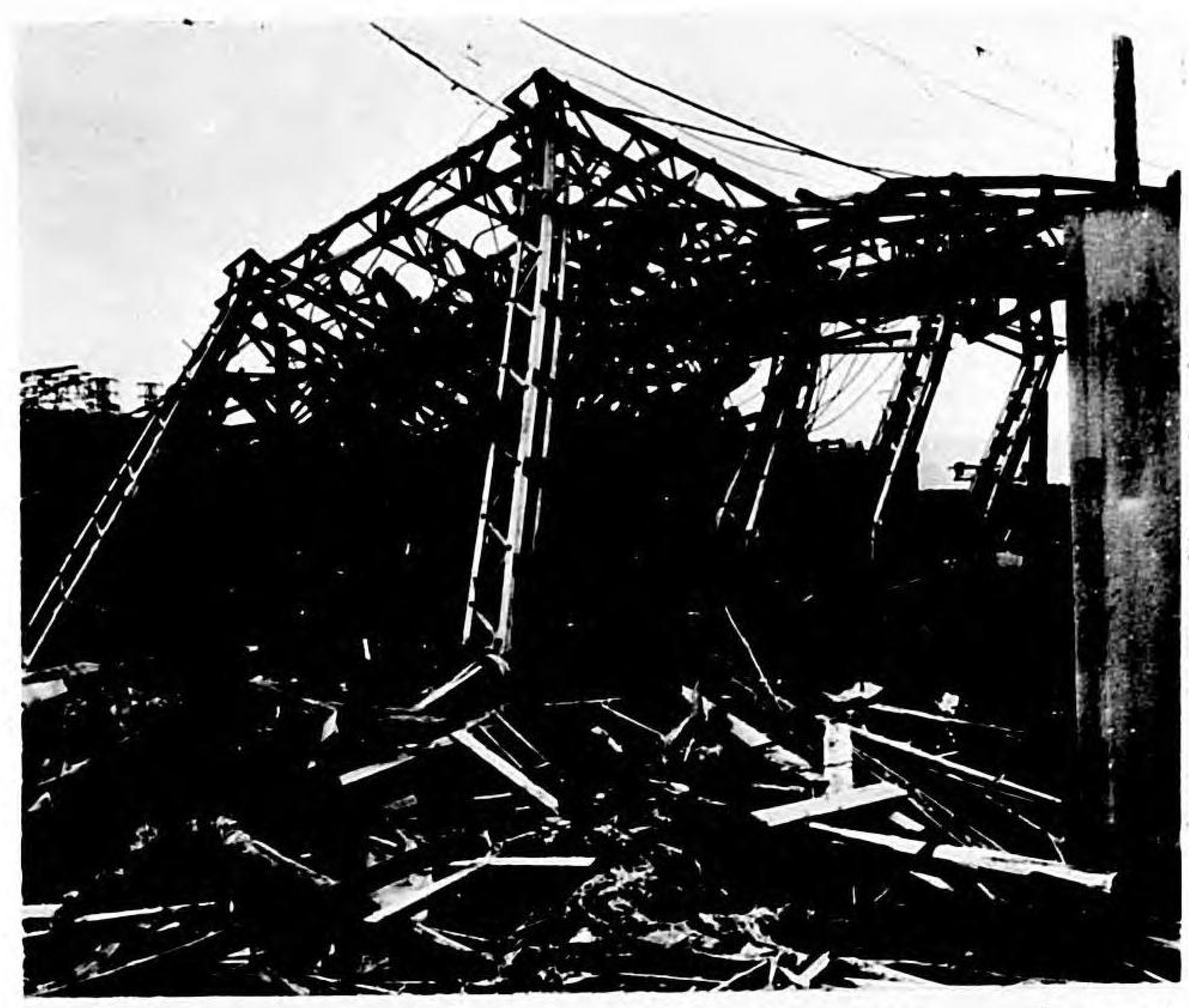


Photo 182. Same as Photo 180. South tower twisted and trusses bent.

in Hiroshima, located 6,500 feet from Ground Zero, having capacities of 316,000 and 211,000 cubic feet, respectively, were damaged when the crowns of the tanks were torn by blast and the released gas ignited. Of the three gas holders at Nagasaki, one located 3,000 feet from Ground Zero was completely demolished by a low-order detonation after being struck by the blast wave, and the other two, 6,500 feet from Ground Zero, had their tops collapsed and sustained heavy structural damage. (Photos 173-174) Total equipment damage at the producing plants was slight. The electrical switchboard and recording meters at the Hiroshima plant were heavily damaged, but there was no loss of other equipment. The retorts and producing equipment at the two coal-gas plants in Nagasaki were affected by blast only to a minor degree. Damage to mains occurred for the most part at bridges and overcrossings. Branch and feeder lines were most heavily damaged at points where they entered buildings and plants within the areas affected by blast and fire. The total effects of the damage to holders, pressure regulators, mains, and pipe lines were sufficient to disrupt completely the gas supply systems at both Hiroshima and Nagasaki, and restoration of service would have required repairs extending over a period of several months.

6. Water Supply. Both Hiroshima and Nagasaki had water supply systems that served their domestic and commercial needs and had always proved adequate for peacetime use. Hiroshima maintained a system capable of furnishing 20,000,000 gallons of filtered water a day. Water was pumped from the Ota River to a large reservoir from which it flowed to the distribution system. Pressure within the distribution system

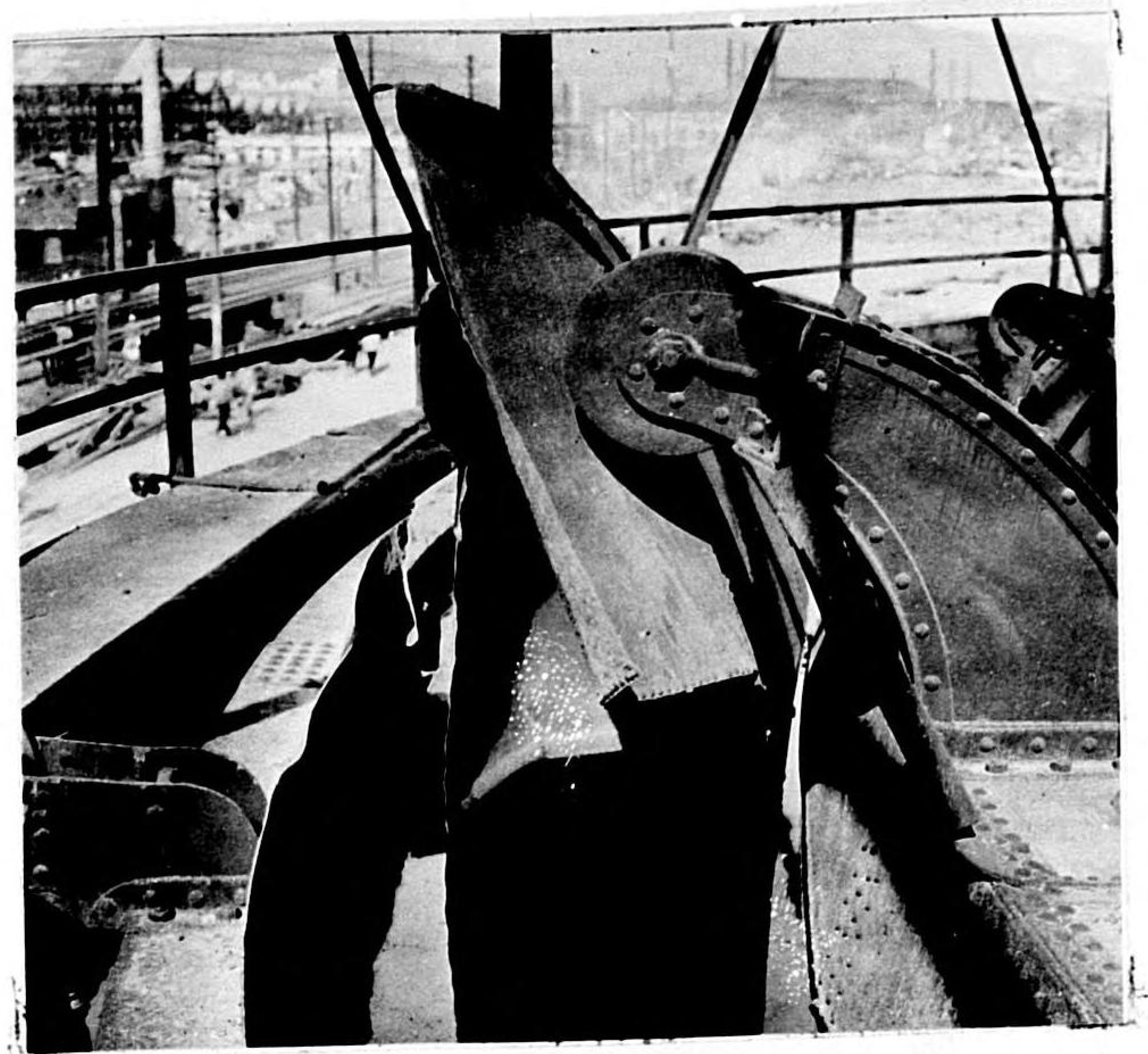


Photo 183. Nagasaki. Yachiyo Machi Gas Works, 6,400 feet from GZ. Broken guide roller on inner gas holder.

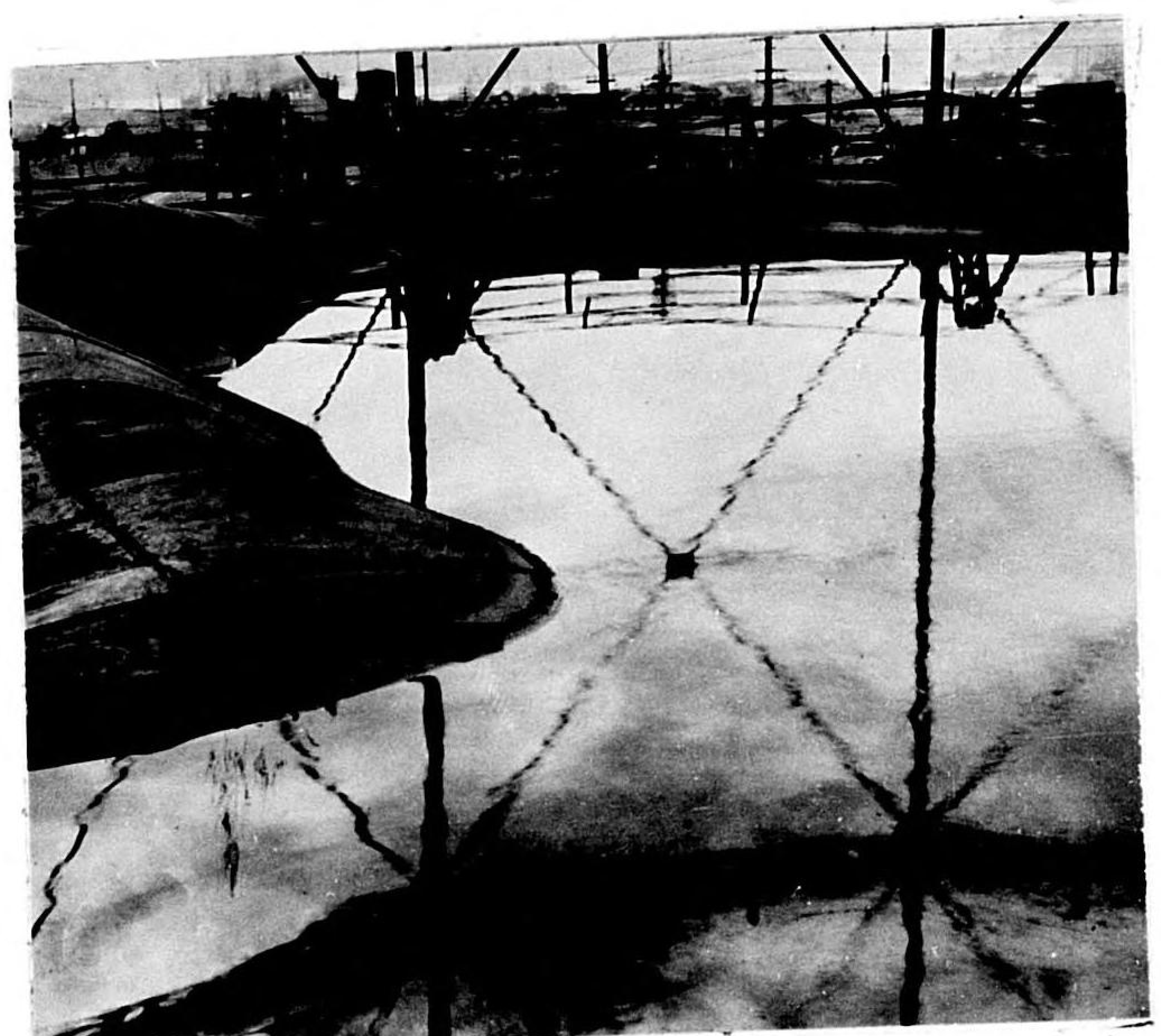


Photo 184. Same as Photo 183. View of top of damaged gas holder.

was maintained by three booster pumping stations. Nagasaki was supplied with water from four reservoirs located within 16,000 feet of Ground Zero. There were four systems with emergency interconnections in operation, each supplied by a different reservoir. Booster stations and pumping equipment in each of the two cities were damaged only slightly; in Hiroshima, a pump motor was burned out because of falling debris, metering equipment in one station was heavily damaged, and several wood-frame buildings which housed equipment sustained structural damage; at Nagasaki, meters housed in wooden structures and the electric installation for pump equipment suffered slight damage. By far the most crippling damage was sustained by distribution pipes and mains. Mains were broken in both cities by displacement of bridges, and additional breaks in Hiroshima's mains were attributed to falling debris. There was no debris damage at Nagasaki, but failure of 12-inch mains three feet below grade occurred as a result of uneven displacement of soil caused by oblique blast pressure. The buried mains in Hiroshima were undamaged. Branch and distribution lines in both cities were heavily damaged by collapsing structures and the heat from burning buildings which melted the pipes. As a result of the damage to the mains and pipes and the consequent leakage and loss of pressure, the supply systems of both Hiroshima and Nagasaki, already taxed to the limit by wartime requirements, were rendered almost useless for fire-fighting purposes within a short period after the attack. Fire-fighting forces therefore relied principally upon bucket brigades which utilized water from domestic wells, water courses, and static tanks. After closing off the supply to those areas where leakage was greatest and to those sections where there would be no demand, sufficient emergency repairs were made within 24 to 36 hours to provide a limited amount of service to meet a portion of the populations' needs.

7. Sewer System. Although the other public utilities in Nagasaki and Hiroshima were roughly comparable in many respects to those in American cities of the same size, the problem of sewage disposal was entirely different. Human excrement was not included in the sewage, but was collected by the city from the residential areas and sold to farmers at a nominal price as a substitute for natural or artificial fertilizers which Japan lacked. The sewer systems, therefore, were maintained primarily for the disposal of domestic waste water and surface drainage. The sewer system at Nagasaki consisted entirely of open trenches and was not considered worthy of study. Hiroshima disposed of 80 per cent of its residential waste water by the use of short laterals to the Ota River; the remaining 20 per cent was carried through branch pipes to the sewer mains. Drainage waters flowed into the river through the mains which also served as storm sewers, and through open flumes. Because the height of the river prevented gravity flow during flood stages, 14 pumping stations had been installed in the system to dispose of waste and surface drainage. The equipment in six of these stations within a 5,200-foot radius of Ground Zero was heavily damaged by blast and subsequent fires at the time of the atomic-bomb attack, and electric motors in two other stations which were damaged by blast were burned out as a result of falling debris. Damage to the electric

substations which powered the pump equipment rendered the undamaged stations inoperative. There was no damage to mains or flumes. Damage to the pumping stations, which was not considered serious at the time, later assumed greater significance as seasonal rains caused floods which seriously delayed repairs of other utilities in Hiroshima, which utilized subsurface systems and manholes.

J. FIRE

1. Vulnerability. The cities of Hiroshima and Nagasaki were both heavily built up, with combustible buildings of Japanese domestic types predominating. Nagasaki was the more congested because of the limitations in expansion placed on it by the surrounding hilly terrain, and its streets were generally narrower. Of the 12-square-mile-built-up part of Hiroshima 68 per cent was 27 per cent or more built up (percentage of roof area to total ground area, excluding parks, fields, rivers and prepared fire breaks), whereas 70 per cent of the 3.8-square-mile built-up area of Nagasaki was 30 per cent or more built up. Probably more indicative of the greater congestion in Nagasaki is the fact that most of the population of 230,000 persons lived in an area of 3.3 square miles, compared to 245,000 persons in 9.9 square miles in Hiroshima. (Only residential areas built up more than 5 per cent ~~were~~ considered.) Except for one light shower in each city, the weather had been dry for a period of three weeks in Hiroshima and for ten days in Nagasaki prior to the atomic-bomb attacks. At the time of the attacks, there was a southeast wind of about 2½ miles per hour in Hiroshima, and a light southwest wind (probably not in excess of 5 miles per hour)

in Nagasaki.

2. Fire Protection

a. Fire Departments. Both Hiroshima and Nagasaki were poorly prepared to combat a conflagration of large-scale proportions, although preparations had been made in both cities to combat mass incendiary attacks. Private fire equipment had been augmented and citizens had been given limited instructions and training in handling incendiary bombs. On the other hand, the public fire departments, which had proved adequate in controlling normal peacetime fires, had not been improved. In fact, in Nagasaki the professional fire-fighting personnel had been reduced 40 per cent. Even in peacetime, however, Nagasaki placed more reliance on auxiliary fire-fighting equipment and personnel than did Hiroshima. Interurban assistance at both cities was quite limited because there were few near-by towns or cities of any size. Industrial plant fire ~~departments~~ brigades, including equipment and personnel, were poor by American standards for ~~cities~~ plants of comparable size.

b. Water Supply. Both cities had combined domestic and fire-service water systems. Water pressure in the central part of each city was normally 40-45 pounds per square inch, but in some places pressure was as low as 5-15 pounds per square inch. Nagasaki had a reservoir capacity of 740,000,000 gallons compared to 4,500,000 gallons in Hiroshima. The water at Hiroshima, however, was pumped from the Ota River, providing an inexhaustible supply, and 20,000,000 gallons of filtered water could be furnished daily. Water flowed to the cities by gravity, booster pumps furnishing the pressure for some areas.

Sizes of water mains and branch lines were comparable in the two cities. Most of the hydrants in both cities were of the below-ground type.

c. Fire Breaks. The Ota River and its six branches divided Hiroshima into nine distinct areas. These river courses and 41,000 feet of fire lanes, which had been prepared by removing combustible buildings on one or both sides of fairly wide streets, provided the city with probably the most extensive network of fire breaks per square mile of any city in Japan. An elaborate system of fire breaks, totalling 55,000 linear feet, had also been cleared in Nagasaki to augment the natural fire breaks provided by Nagasaki Bay and the Urakami and Nakashima Rivers.

3. Start of Fires

a. Hiroshima. The explosion of the atomic bomb at Hiroshima started hundreds of fires almost simultaneously throughout the heavily built-up city center. The original fires were most numerous within 4,000 to 5,000 feet of Ground Zero, ~~since~~ because the buildings in this area were closer to the center of heat, there were more of them, and a larger percentage was collapsed by blast. The temperature at the center of the bomb explosion was of extreme intensity (estimated at 70,000,000° C), but because the heat had largely dissipated before reaching ground objects, the temperature at Ground Zero probably was only in excess of 3,500° C for a fraction of a second. Apparently this flash heat started numerous fires in easily ignitible materials such as dark cloth, thin paper, and dry-rotted wood, principally within 3,500 feet from Ground Zero. Most of the initial fires, however, were started by secondary sources of ignition, such as kitchen charcoal fires, electric short circuits, and industrial process fires, through the collapse of combustible buildings and in debris created by blast.

b. Nagasaki. The Nagasaki bomb was more powerful than the Hiroshima bomb and was detonated somewhat nearer to the ground. For these reasons the intensity of the heat at Ground Zero exceeded that at Hiroshima, and, in proportion to the amount of combustible materials exposed, radiant heat from the Nagasaki bomb is believed to have started more fires. In addition, there were hills within 2,000 feet of Ground Zero which placed buildings, trees, and other objects on them closer to the point of detonation, and directly exposed a greater proportion of the interiors of the buildings to radiant heat from the bomb. Wooded hillsides 1,000 to 2,000 feet west of Ground Zero in Nagasaki were ignited by radiant heat. In both cities, exposed, vitreous roof tiles were blistered, granite was spalled and roughened, and wood, asphalt, and asphalt-painted surfaces were flash burned at various distances from Ground Zero depending upon their susceptibility to heat.

4. Fire Spread. There was a relatively small amount of fire spread in both cities beyond the areas in which the original fires were ignited by radiant heat from the bomb and secondary sources. A fire storm, including both wind and rain, developed in Hiroshima soon after the start of the original fires. The wind, which blew from all directions toward the burning area, reached a maximum velocity of 30 to 40 miles per hour about two to three hours after the explosion. Light and heavy rain fell intermittently over the north and west parts of the city. The fire storm was a decisive factor in limiting fire spread in

directions away from the city at the fire perimeter. The high winds were caused by the fires drawing in a fresh supply of oxygen over the flat terrain, and the rain resulted from the condensation of moisture on particles of hot carbon which had been blown northwestward by the light, natural, southeast wind. Although a distinct fire storm did not develop in Nagasaki, the velocity of the southwest wind, directly up the bay between the hills, had increased to about 35 miles per hour when the conflagration had become well established, probably about two hours after the explosion. About nine hours after the explosion the wind had shifted to the east, but its velocity had diminished to 10 to 15 miles per hour. The southwesterly wind is believed to have assisted in stopping fire spread to the south on both sides of the bay, and the shift of the wind to the east may have limited fire spread in the Nakashima River valley. No rain was reported to have fallen over the city. The long, narrow shape of the Urakami River valley and the hills which lined both sides of it were not so conducive to development of a fire storm as the broad flat terrain of Hiroshima. There was a natural tendency for the fires to sweep up the hills, which they did, and to draw a fresh supply of air from the south up the center of the narrow area formed by the river and the sites of noncombustible industrial plants on its east bank. This narrow corridor varied in width from 500 to 2,000 feet, and extended from just southwest of Ground Zero all the way south to the bay. Apparently it acted as a funnel through which a fresh supply of air from the south could reach the burning areas on each side of the Urakami River, and this accounted for the great increase in wind