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VOLUME II.

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NAGASAKI ATOMIC BOMB DAMAGE
Nagasaki, Japan

9 August 1945 (Japanese Time)

UNITED STATES
ATOMIC ENERGY COMMISSION
OAK RIDGE, TENNESSEE

This document has been reviewed and it has been
determined that it does not contain Restricted Data
as defined in the
Atomic Energy Act of 1954.

John
AUG 31 1961 *R. J. C.*

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THIS DOCUMENT CONSISTS OF 62 PAGES
NO. 2 OF 13 SERIES A

NAGASAKI ATOMIC BOMB DAMAGE

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NAGASAKI ATOMIC BOMB DAMAGE

V. DAMAGE TO STRUCTURAL STEEL-FRAME BUILDINGS.

The two most important targets at Nagasaki, the Mitsubishi-Urakami Ordnance Works and the Mitsubishi Steel and Arms Works, were primarily structural steel frames with roof and siding of either corrugated metal or corrugated asbestos. The construction was comparable to mill construction in America, except that some of the steel frames were lighter than would have been used in this country. The construction employed by the Japanese, however, shows that they were short of steel and resorted to numerous expedients to save metal, among which was the extensive use of "built-up" members of light steel or the use of wood in lieu of steel wherever feasible.

Figures 73 to 76, inclusive, depict destruction at the Mitsubishi-Urakami Ordnance Works, which was devoted primarily to the manufacture of torpedoes. The destruction at this large sprawling factory was even greater than at the Mitsubishi Steel and Arms Works, which was closer to zero point.

Figure 17, is an aerial view of the Mitsubishi Steel and Arms Works. The North end was approximately 3/10 miles South of zero point and the plant extended along the East bank of the Urakami River

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MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles North of Zero Point)

An aerial view showing destruction or very severe damage to almost every building. Note that many of the buildings are almost completely flattened into a mass of twisted steel and broken timber. The buildings in this ordnance works were, in general, of much more flimsy construction than those at the Mitsubishi Steel and Arms Works. Note, also, that the reinforced concrete research laboratory building, located in the right foreground, is still standing. It sustained only moderate damage.

FIGURE 73

MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles North of Zero Point)

Copy of a Japanese photograph. View looking Southeast from a point about a mile North of zero point. Dark building in right background is Research Laboratory Building (Administration Building) of reinforced concrete. Buildings in foreground are workers dwellings destroyed by the blast. Note very severe damage to all factory buildings.

(Picture by W. G. Penney)

FIGURE 73A

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MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles North of Zero Point)

Close-up of wreckage showing combined use of steel and
wood. Japanese were short of metal.

(Picture by W. G. Penney)

FIGURE 73B

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MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles North of Zero Point)

Copy of Japanese photograph. View looking Northeast from Research Laboratory (Administration) Building. Note wreckage of light steel frame buildings. Dwellings in background were damaged but not completely wrecked.

(Picture by W. G. Penney)

FIGURE 73c

MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles North of Zero Point)

Another view looking North from the Research Laboratory (Administration) Building, 0.8 miles from zero point.

(Picture by W. G. Penney)

FIGURE 73D

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MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles North of Zero Point)

Copy of Japanese photograph. Looking North from Research Laboratory Building (Administration), showing wreckage of steel frames. Note collapsed structural steel roof of concrete building in foreground.

(Picture by W. G. Penney)

FIGURE 73E

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MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles North of Zero Point)

Wreckage of steel-frame buildings 0.8 to 0.9 miles from zero
point.

(Picture by W. G. Penney)

FIGURE 73F

MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles North of Zero Point)

Interior view of shop building approximately 0.9 miles from zero point, showing wreckage. This building is a complete loss. Note the extremely light steel construction and the extensive use of wood. This building was one of the flimsiest of the various Mitsubishi shop buildings. Note that no fires developed.

FIGURE 74

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MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles from Zero Point)

This view shows the failure of a very large factory building with saw-tooth roof truss 0.9 miles from zero point. These trusses were very flimsily constructed of light angles; the trusses had a span of approximately 30-feet and were spaced about 20-feet apart. The purlins were of wood, 4-inches by 5-inches, spaced on about 24-inch centers. The roof and siding consisted of 1-inch lumber, covered with corrugated asbestos, which, in turn, was covered with camouflage cloth. The roof failed from the thrust of the bomb blast, which collapsed the purlins and caused the roof to fall in generally. The upper chords of many of the roof trusses also failed. The buildings, in general, at the torpedo works, were flimsy in construction and the damage was quite severe.

FIGURE 75

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MITSUBISHI-URAKAMI ORDNANCE WORKS
(Torpedo Works)

(From 0.7 to 1.0 Miles North of Zero Point)

Interior view of one of the machine shops approximately 0.9 miles from zero point, showing badly damaged structural steel framework. Note that siding and roofing were stripped by the blast. Reinforced concrete Pill-Boxes in this building (aisle in center of picture) indicates that prison labor was used here.

FIGURE 76

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V. DAMAGE TO STRUCTURAL STEEL-FRAME BUILDINGS. (Continued)

to a point approximately 1.2 miles South of zero point. Besides the reinforced concrete office buildings and the concrete arch-roof buildings already described, the plant consisted of typical structural steel-frame mill construction with corrugated metal or asbestos roof and siding. The damage varied with the proximity to zero point and the strength of the structural steel frame. Some of the buildings, in addition to being stripped of roof and siding, were completely wrecked, while the frames of some of the stronger buildings sustained only minor damage. Damage to building contents was significant in all cases. Figures 77 to 90, inclusive, show general and specific damage to various buildings at the Mitsubishi plant. Figures 91 to 101, inclusive, show specific damage to one of the foundry buildings of the Mitsubishi Steel and Arms Works, approximately 3/10 miles South of zero point. The size and spacing of the various steel members are shown and the type of failure depicted and explained. Figures 101a to 101c, inclusive, show damage to Mitsubishi Woodworking Plant and to Akunoura Engine Works located 1.2 miles and 2 miles, respectively South of zero point.

As previously pointed out, the rapid stripping of roof and siding from buildings with steel frames lessened areas facing the blast wave, greatly reduced total pressures against the sides and roofs, and thereby saved many of such buildings from complete collapse.

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

View of a portion of the plant taken from West bank of Urakami River showing severe damage to light steel frame work. Roof and siding of corrugated iron were stripped and windows knocked out by the blast.

FIGURE 22

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

View approximately 3/4 of a mile from zero point, showing heavy steel frame work stripped of roof and siding, but only slightly injured by the blast. Reinforced concrete office building sustained only minor damage.

FIGURE 78

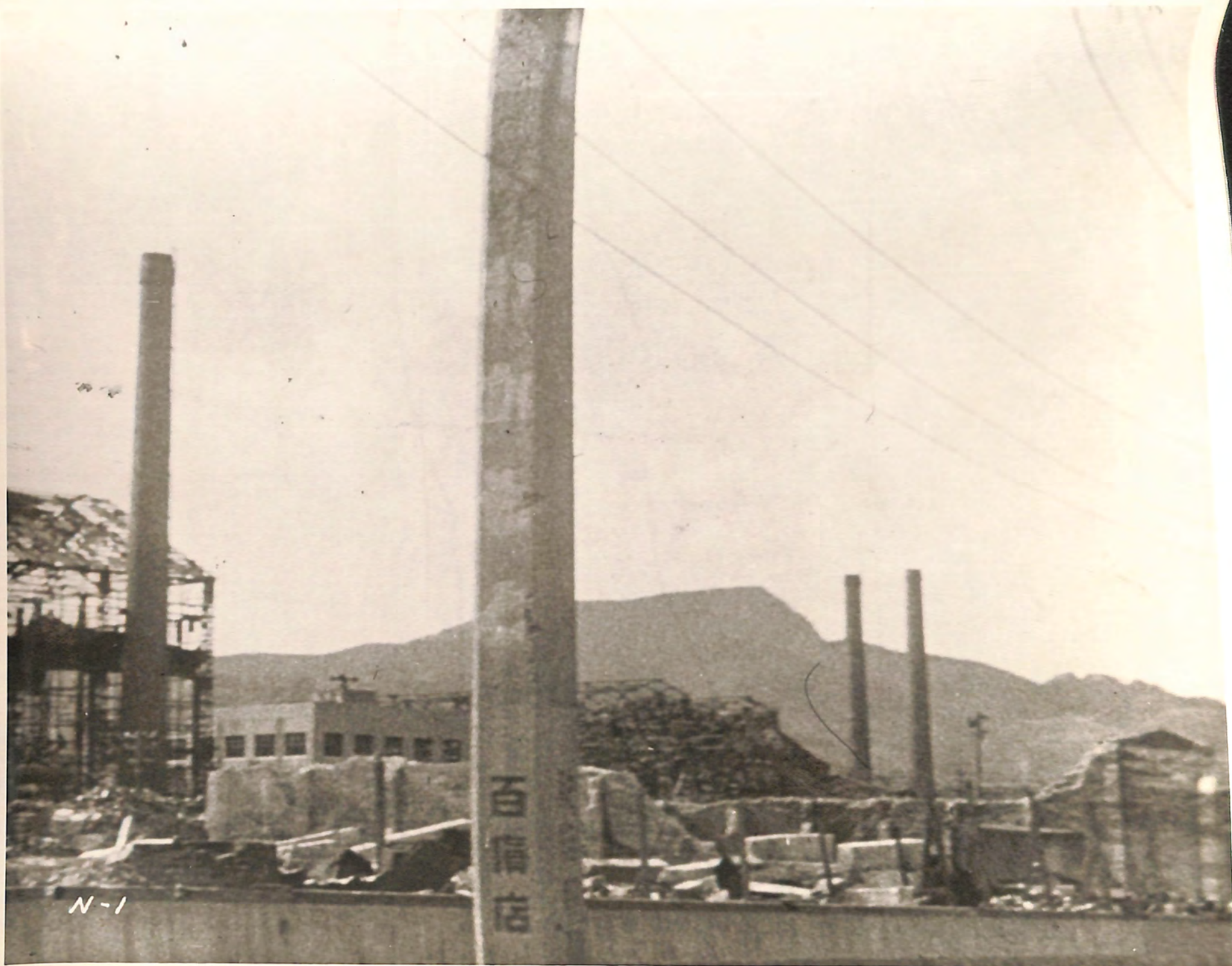
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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

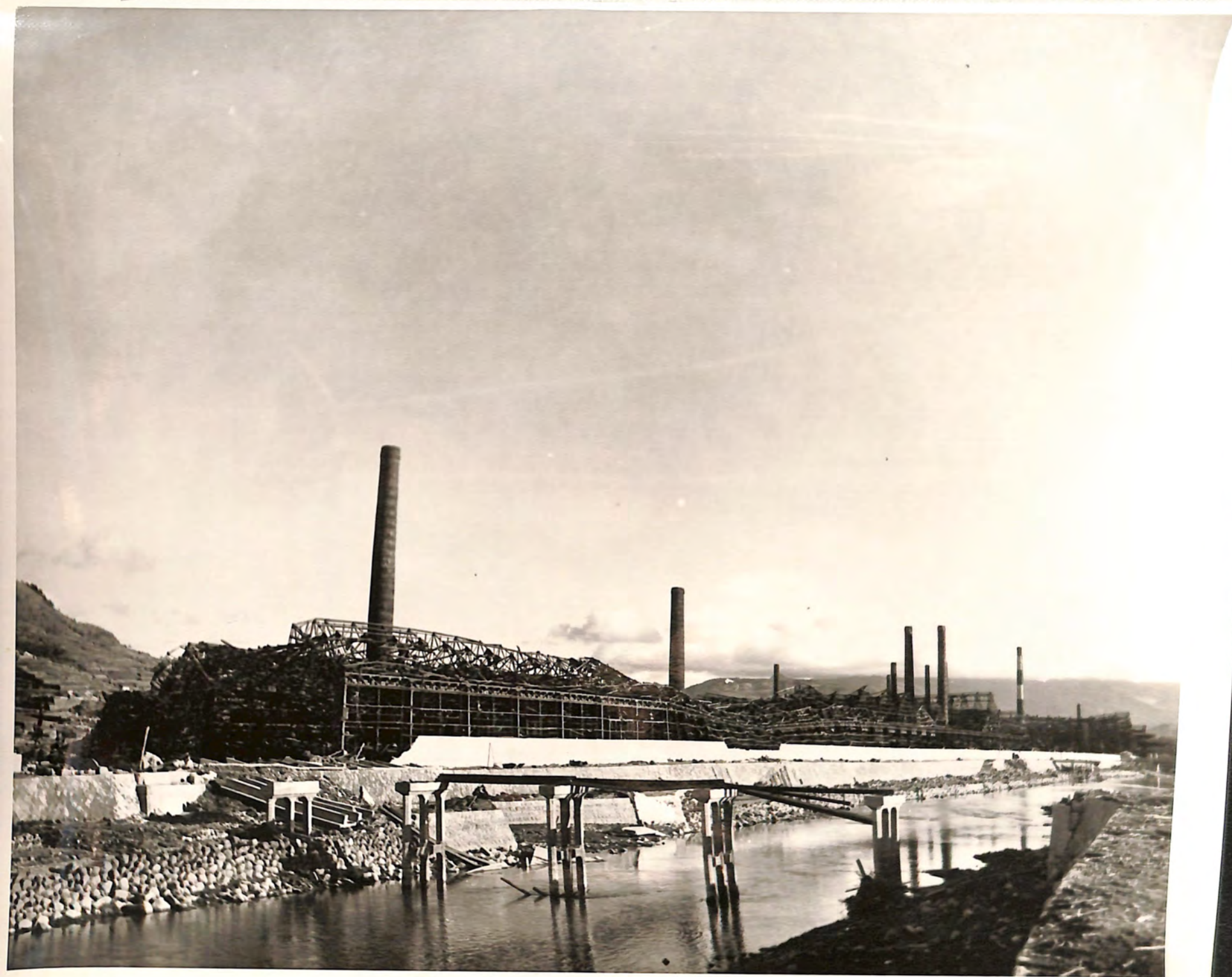
The group of buildings comprising the Mitsubishi Steel and Arms Works extended almost a mile in length, the closest building being approximately 0.3 of a mile South of zero point. Most of the buildings were constructed of a structural steel frame with corrugated asbestos or corrugated iron roof and siding, typical of factory construction in the United States and other countries. This view shows severe damage to a group of buildings from 0.4 to 0.5 of a mile South of zero point. The reinforced concrete chimney on the left (closest to zero point) was cracked by the force of the blast. The other chimneys shown in this picture were apparently uninjured. The concrete and steel I-beam bridge across the Urakami River, shown in the foreground, was destroyed by the blast, leaving only the concrete piers and abutments.

FIGURE 79

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MITSUBISHI STEEL AND ARMS WORKS

(From .3 to 1.2 Miles from Zero Point)

This view shows destruction to steel frame buildings at a distance of approximately .6 of a mile from zero point. Note remnants of corrugated siding and roofing still clinging to the steel frame.

FIGURE 80

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

This is a view of the interior of one of the heavy machine shops. Note that although the steel frame sustained minor damage, the corrugated iron roof and siding were stripped by the blast.

FIGURE 81

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

Interior view of heavy machine shop about 3/4 of a mile from zero point. This building was built strongly to support overhead cranes and heavy loads and the framework was only slightly damaged by the blast. Corrugated iron roof and siding were stripped by the blast and windows were knocked out. While building contents were tumbled and damage to equipment is significant, it is not believed to be very serious. The main damage to heavy equipment like this is from rust.

FIGURE 82

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

Interior view of one of the heavy machine shops about 0.7 miles from zero point. Note the heavy steel construction to carry overhead cranes. The steel framework was only slightly injured, but corrugated roofing and siding were stripped by the blast.

FIGURE 83

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

This is a general view of damage caused by the blast to buildings in the South portion of the plant. Note the corrugated metal ripped from the steel frame work and damage to building contents. Reinforced concrete chimneys at this location were apparently uninjured.

FIGURE 84

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

View of foundry and heat treatment shops (left) and machine shops (right) taken from West bank of Urakami River about 3/4 of a mile South of zero point, looking East. Note that while portions of these buildings were completely wrecked, other parts were not seriously damaged except for stripping of roof and siding.

(Picture by W. G. Penney)

FIGURE 84A

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

View of foundry and heat treatment shops (left) and machine shops (right) taken from West bank of Urakami River about 3/4 of a mile South of zero point, looking East. Note that while portions of these buildings were completely wrecked, other parts were not seriously damaged except for stripping of roof and siding.

(Picture by W. G. Penney)

FIGURE 84A

MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

A close-up of wreckage to light steel frame work from 0.4 to 0.5 miles South of zero point. These buildings received the blast wave on their tops and sides. Roof and siding were of corrugated iron.

(Picture by W. G. Penney)

FIGURE 84B

MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

Damage approximately 1/2 Mile South of zero point. Note
heavy presses in background.

(Picture by W. G. Penney)

FIGURE 84c

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

Interior view of wreckage in large foundry and heat treatment shop, approximately 3/4 of a mile South of zero point.

(Picture by W. G. Penney)

FIGURE 84D

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

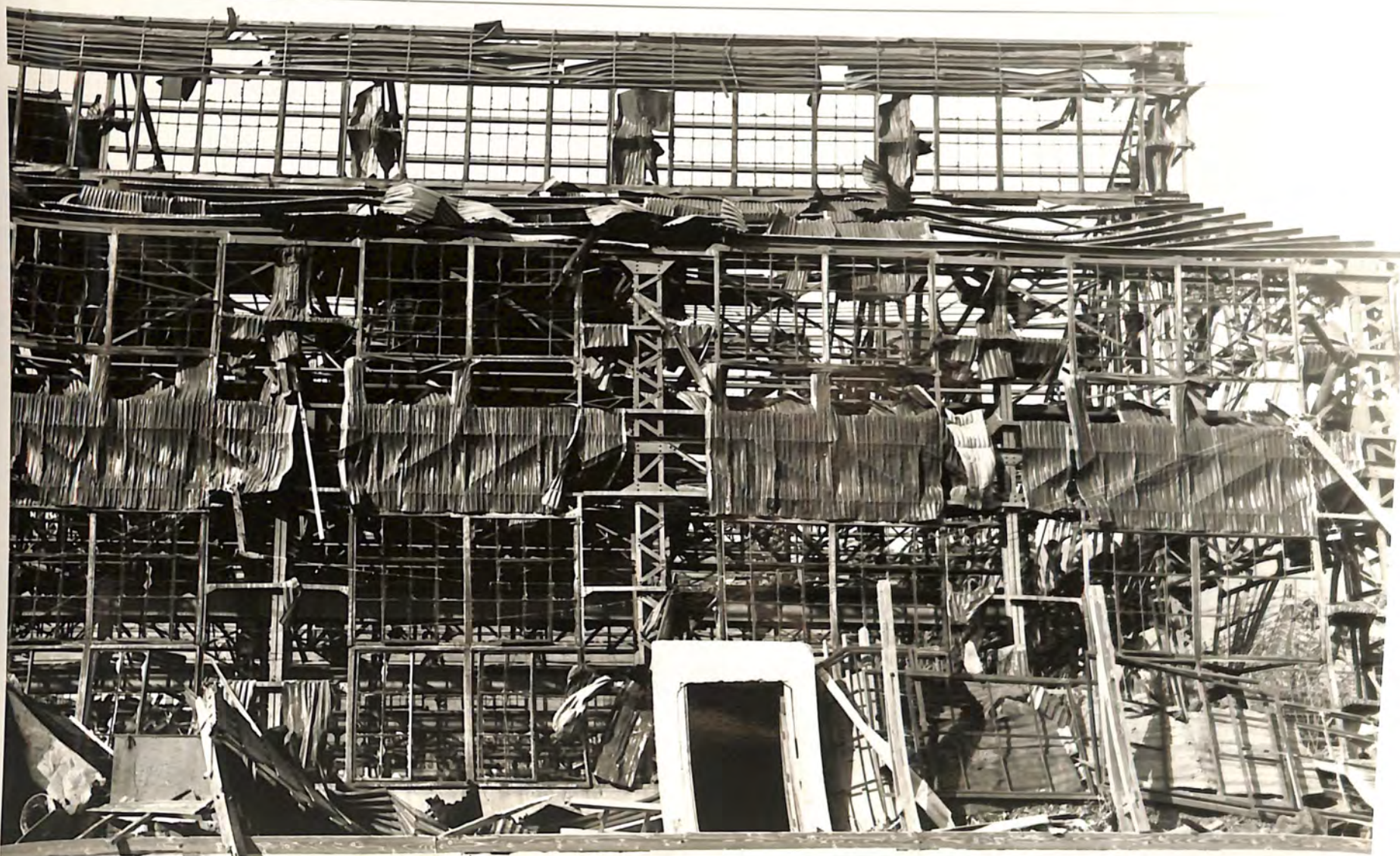
This picture shows damage sustained by one of the more strongly constructed buildings at a distance of approximately 0.9 of a mile from zero point. Note that, while windows were knocked out and window sash was damaged, the steel frame sustained only minor damage. Note, in particular, how the corrugated iron roof and siding remaining on the building is mashed against or wrapped around the steel framework by the force of the blast as though it were tissue paper.

FIGURE 85

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

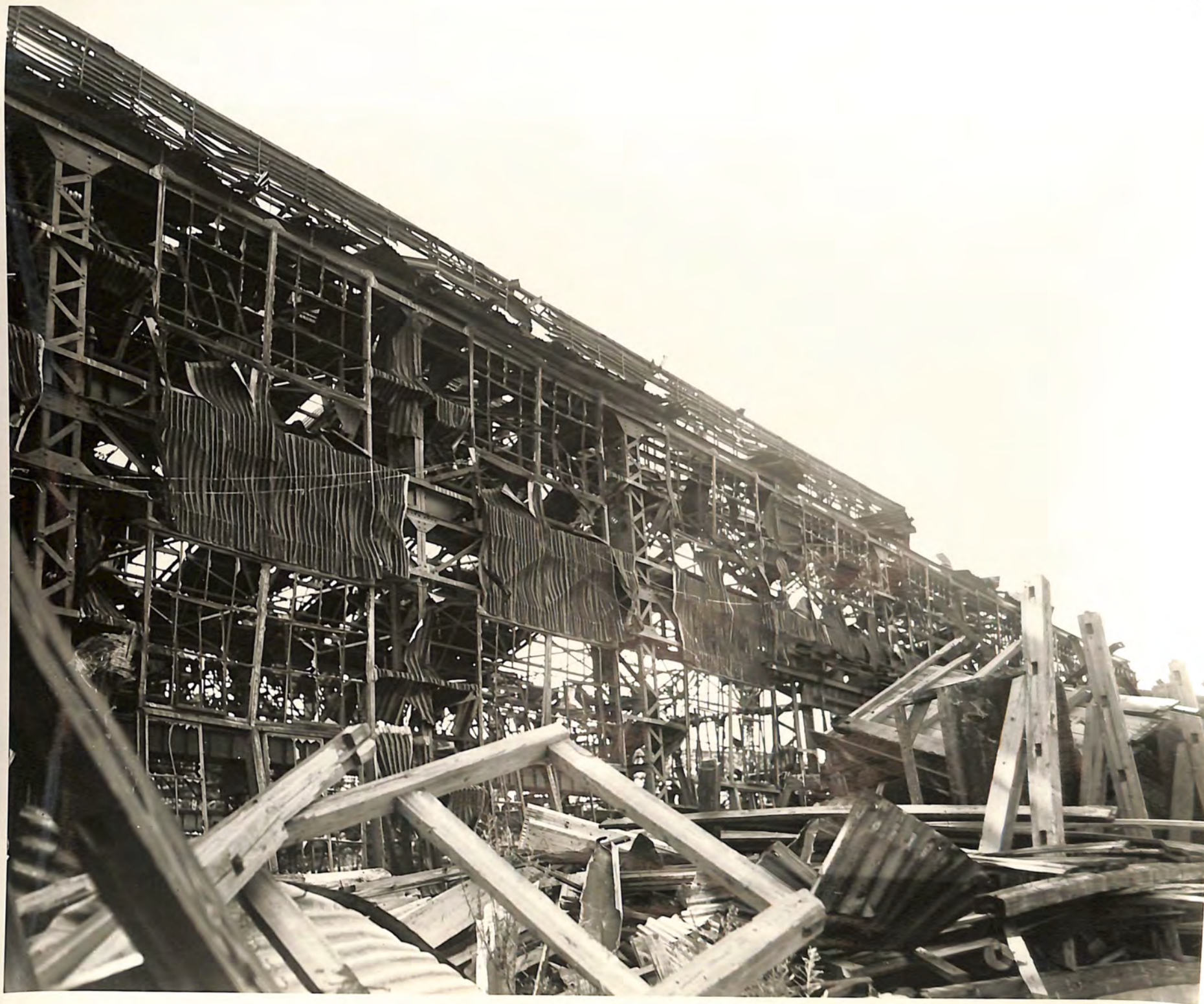
This building was approximately 0.8 of a mile from zero point. Note that corrugated iron siding and roofing has been stripped from a large part of the steel frame work. Siding remaining is pressed against or wrapped around the framework like tissue paper. Also, note the complete collapse of the heavy wooden structure alongside the steel frame building and that it did not catch fire.

FIGURE 86

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

This view shows the top of a metal cabinet dished in
by the force of the blast.

FIGURE 87

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

This view shows the collapse of the first floor of a reinforced concrete building. First floor of the building was supported by a structural steel frame. The failure was caused by the collapse and failure in bending of relatively light wall columns. Occupants in this building (about 3/4 mile from zero point) who were not killed in the wreckage, were shielded from Gamma radiation, while occupants in the adjoining building, with corrugated metal roof and siding, were injured by this type of radiation.

FIGURE 88

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

This is another view, showing failure of concrete and structural steel building.

FIGURE 89

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

This building was approximately 0.9 miles from zero point, and shows the failure of wall columns which caused the collapse of the reinforced concrete and structural steel roof.

FIGURE 90

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

This is a view of one of the foundry buildings approximately 0.3 of a mile from zero point. It shows the damaged steel frame, stripped of roof and siding. Note that both chimneys have been broken off by the blast shortly above the roof level.

FIGURE 91

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

View showing damage to light steel frame approximately 0.3 miles from zero point. Roof and siding were stripped by the blast.

FIGURE 92

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MITSUBISHI STEEL AND ARMS WORKS.

(From 0.3 to 1.2 Miles South of Zero Point)

A foundry building approximately 0.3 of a mile from zero point. This is an interior view looking North toward zero point, showing how castings, moulds, and building contents in general were tumbled by the blast. The North end of the building, of light angle iron construction, was caved in by the blast wave. The tops of the columns were shoved in the direction of the blast from 18 to 25-inches, causing buckling of the tops of the columns and failure of their concrete foundations. Note, also, the small pieces of corrugated asbestos roofing and siding broken up by the blast.

FIGURE 93

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

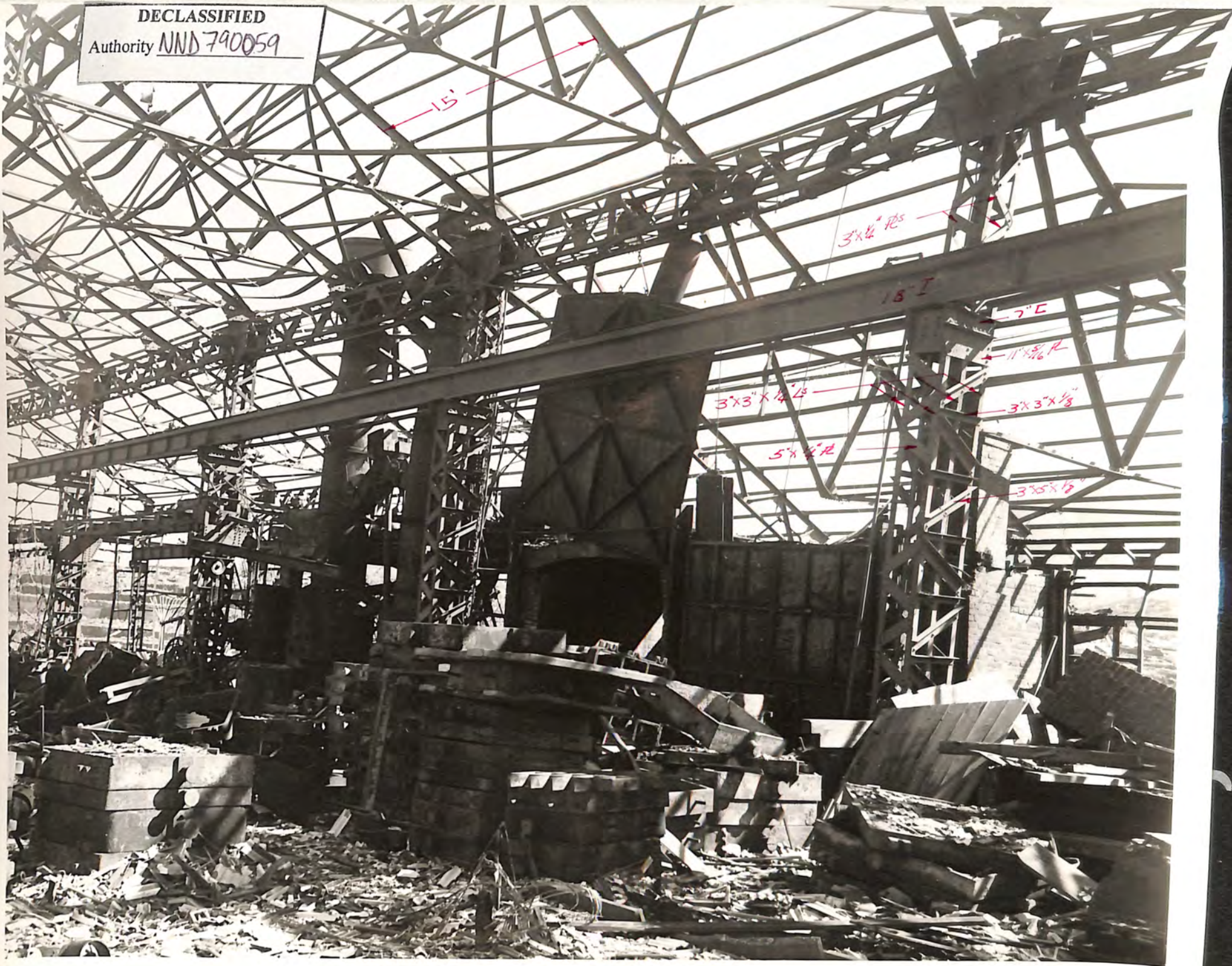
A foundry building approximately 0.3 of a mile from zero point. Interior view looking toward zero point showing molds for castings and furnaces. Two light steel chimneys were toppled by the force of the blast onto the roof purlins and roof trusses and caused damage where they fell. The force of the blast shoved the top of the building 18-inches to 25-inches to the South (right, in this picture), buckling the top portion of the columns and either cracking or rotating the concrete foundations for the columns. No fires occurred in this building, although the heat of the blast was, undoubtedly, severe at this distance.

FIGURE 94

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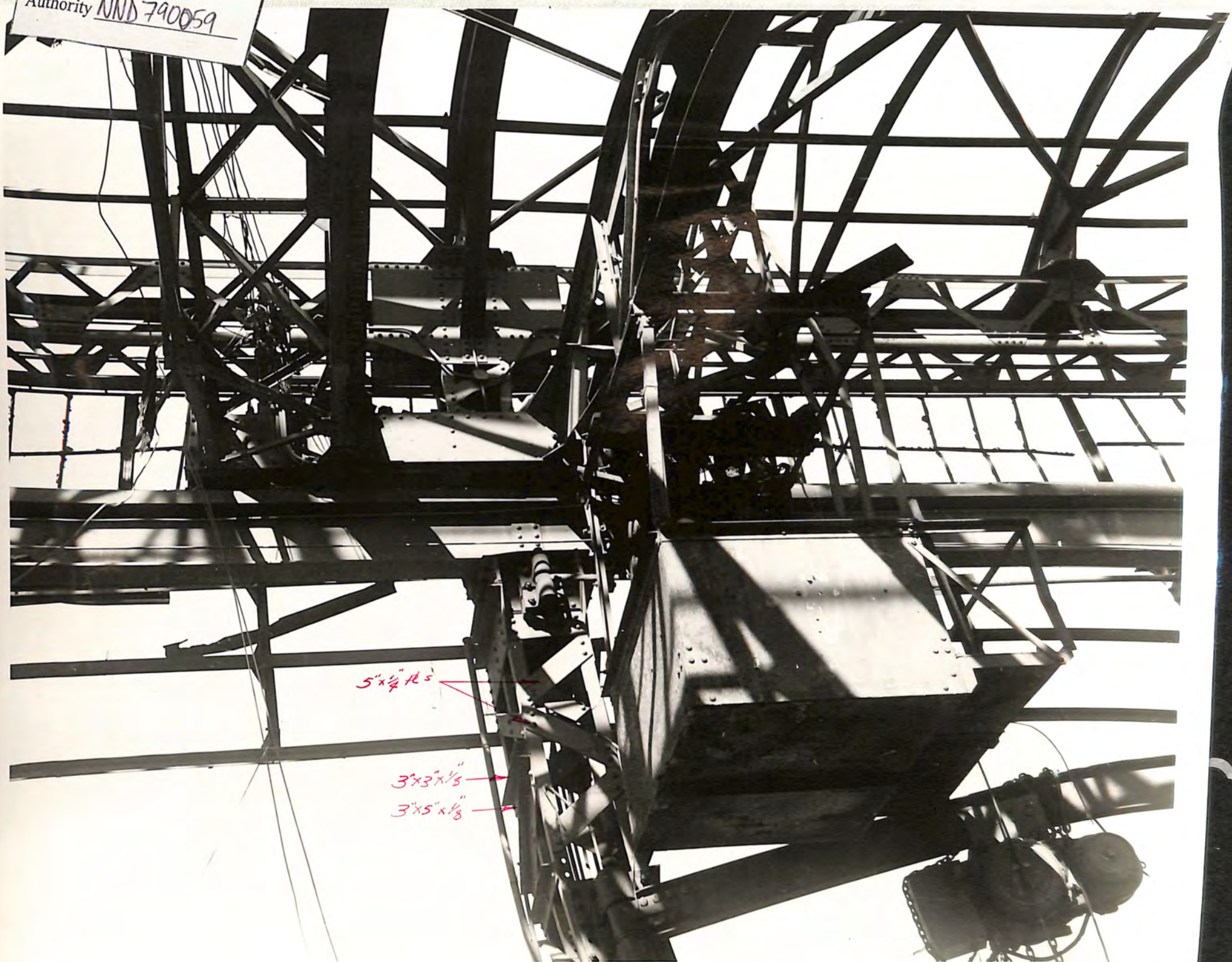
MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

A foundry building approximately 0.3 miles from zero point. This is a side view of a typical column taken from the ground looking up to the roof truss. Note that the column is connected to the roof truss and to the truss beams connecting the columns by means of heavy gusset plates 5/16" in thickness. Also, note that the portion of the column between the roof truss and the rail for the crane has been buckled by the force of the blast, acting from the right (in this picture). This view also shows the crane and operator's cab.

FIGURE 75

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5" x 1/4" PL

3" x 3" x 1/8"

3" x 5" x 1/8"

MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

Foundry building approximately 0.3 of a mile South of zero point. This view shows a typical column and connections. Note that column consists of six angles laced together with steel straps from the base up to the point where the rail for the overhead crane is supported and that from this point to the roof truss the column is reduced to four angles laced together. The connection to the double truss beam supporting the roof trusses is made secure by the use of heavy gusset plates. It will be noted that the column is buckled at the section consisting of only four angles. This was caused by induced moment as the blast struck the building from the right (in this picture).

FIGURE 96

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

A foundry building approximately 0.3 of a mile from zero point at the North end of the Mitsubishi group. This picture shows a close-up of a typical column. The column is composed of six angles, each 3" x 3" x 1/4", stiffened and laced with 3" x 5" x 1/8" angles and 5" x 1/4" plates. This type of built-up column requires a great deal of time and labor for fabrication, but the Japanese were very short of steel and they probably used this type of construction since it requires less material than other types.

FIGURE 97

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

A foundry building approximately 0.3 of a mile from zero point. This view shows typical columns along the West side of the building. Note that the rail for the overhead crane is carried by the columns and that from the rail to the roof truss, the column is reduced in size from six angles laced together to four angles laced together. Also, note that corrugated asbestos roof and siding have been stripped by the force of the Atomic blast and that all windows have been knocked out.

FIGURE 98



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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

A foundry building approximately 0.3 of a mile from zero point. This is a close-up of the concrete foundation for a typical structural steel column, showing crack caused by induced moment which resulted from the blast, acting from the right (in this picture). In those instances where the foundation did not crack as shown here, the concrete foundation was rotated; that is, it was caused to rise on one side and to lower on the other side. Note the small pieces of corrugated asbestos roofing and siding broken by the blast. Also, note the large amount of combustible matter and tinder which did not burn or char even though relatively close to zero point.

FIGURE

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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

A foundry building approximately 0.3 miles from zero point. This is a general view looking up to the steel roof trusses. Note that while the corrugated asbestos roofing has been stripped by the blast and some of the steel purlins have been bent, the roof trusses themselves suffered only minor damage.

FIGURE 100

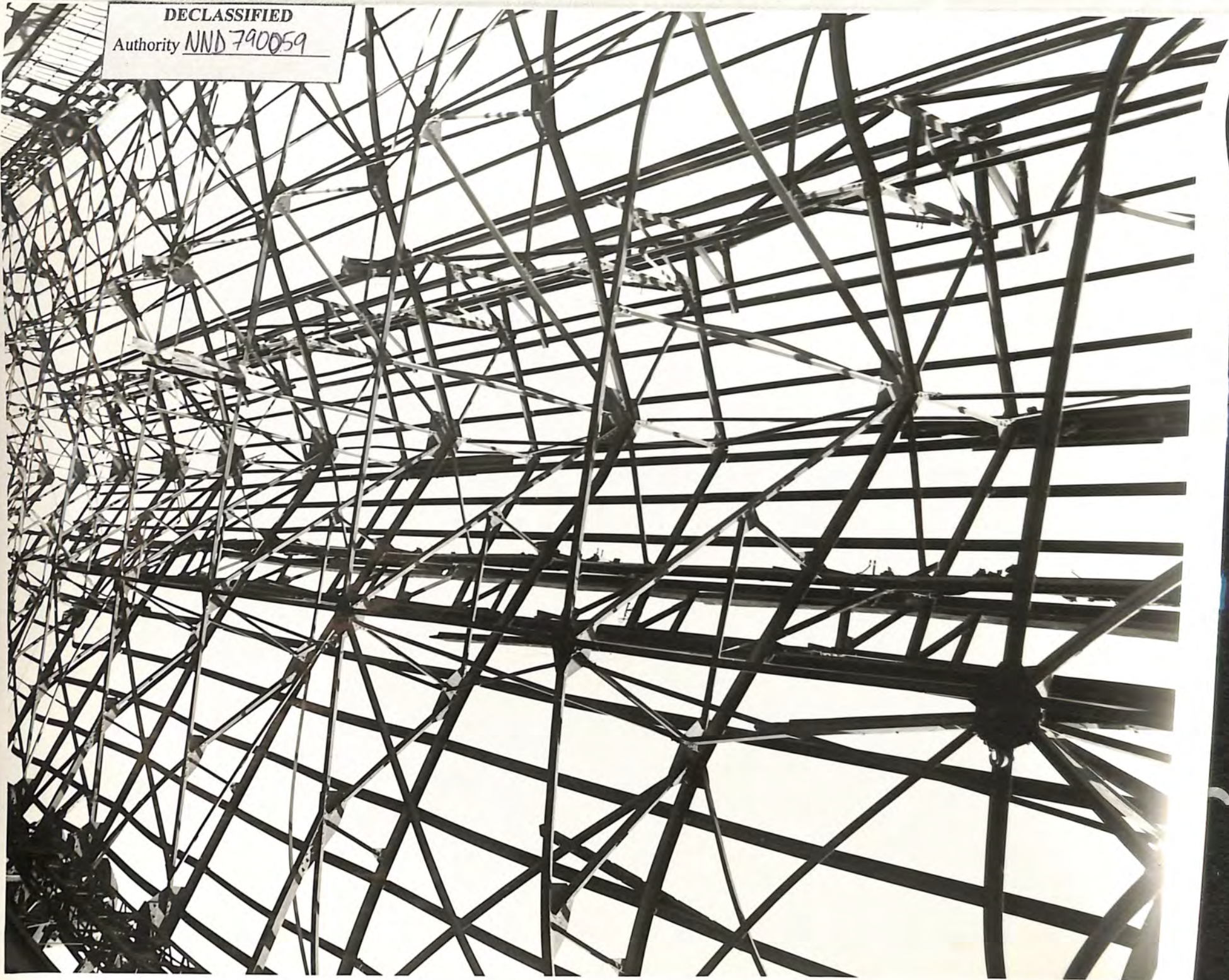
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MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles from Zero Point)

Foundry building approximately 0.3 of a mile from zero point.
This view shows the light steel construction in the furnace room.
Note how the wall columns failed at the tops and bottoms from
negative moment induced by the blast.

FIGURE 101

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MITSUBISHI WOODWORKING PLANT

(Approximately 1.2 Miles South of Zero Point)

This plant, located on the West bank of the Urakami River,
was severely damaged by blast and fire - practically a total loss.

(Picture by W. G. Penney)

FIGURE 101A

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AKUNOURA ENGINE WORKS

(Approximately 2 Miles South of Zero Point)

View showing buildings stripped of roofing, windows broken out, window frames bent, etc. Note concrete "pill box" in right center.

(Picture by W. G. Penney)

FIGURE 101 B

AKUNOURA ENGINE WORKS

(Approximately 2 Miles South of Zero Point)

These steel-framed factory buildings on the West bank of the Urakami River were stripped of roof and siding, some of roof purlins were bent, windows broken, window frames ripped out or twisted. Crane was not damaged other than broken windows in operators cab.

(Picture by W. G. Penney)

FIGURE 101 c

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NAGASAKI ATOMIC BOMB DAMAGE

VI. DAMAGE TO MASONRY BUILDINGS.

Almost without exception masonry buildings of either brick or stone, within the effective limits of the blast, were very severely damaged with most of them being flattened or reduced to rubble. The wreckage of the Roman Catholic Church, approximately 0.4 miles East of zero point, was one of the few masonry buildings still recognizable and only portions of the walls were left standing. (See Figure 30). The walls of this structure were extremely thick (about 2-feet). The two domes of the church had reinforced concrete frames and although they were toppled by the blast, they held together as units. Although masonry buildings were almost totally wrecked by the blast, they provided rather effective shielding of occupants from gamma radiation, however, many of the occupants in such buildings were killed or severely injured as the buildings collapsed. Figures 102 to 107, inclusive, show damage to the church. Figure 108 to 108c, inclusive, shows damage sustained by masonry factory buildings, etc., at various distances from zero point.

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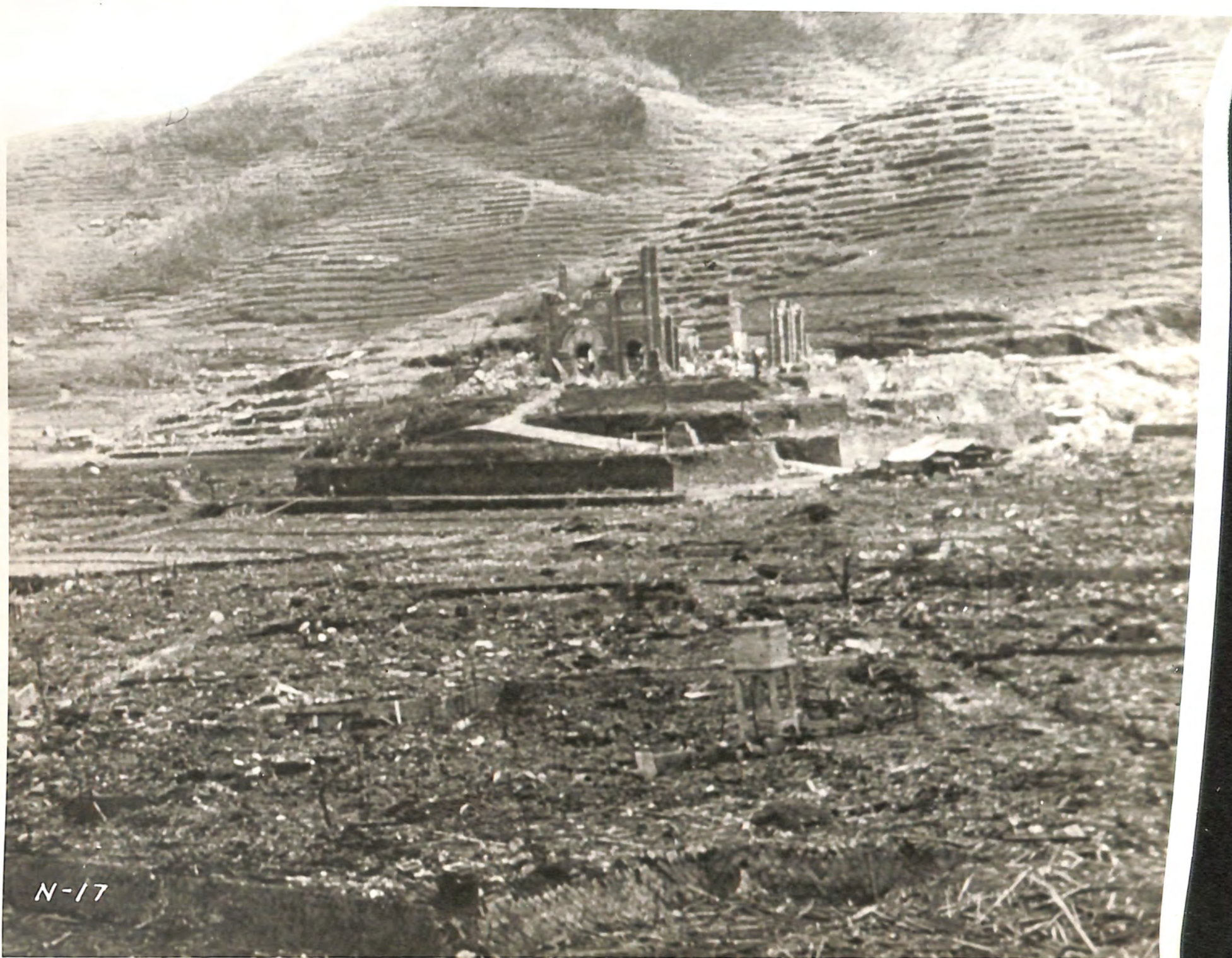
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CATHOLIC CHURCH

(Approximately 0.4 Miles Northeast of Zero Point)

This building, wrecked by the blast, was of heavy masonry construction (very thick brick walls). Note steep hills which confined the blast effects largely to the industrial valley.

FIGURE 102



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CATHOLIC CHURCH

(Approximately 0.4 Miles Northeast of Zero Point)

General view of wreckage. The large expanse of walls with few openings offered great resistance to the blast wave and contributed to the failure even though the walls were massive brick.

FIGURE 103

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CATHOLIC CHURCH

» (Approximately 0.4 Miles Northeast of Zero Point)

View of wreckage showing heavy masonry (brick) walls.

FIGURE 104

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CATHOLIC CHURCH

(Approximately 0.4 Miles Northeast of Zero Point)

Close-up of a wall left standing, showing failure of heavy masonry (brick) construction.

(Picture by W. G. Penney)

FIGURE 104A

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CATHOLIC CHURCH

(Approximately 0.4 Miles Northeast of Zero Point)

View of wreckage from Atomic blast, showing heavy brick construction. This building would probably have been no more completely wrecked had a large high explosive bomb scored a direct hit. The reinforced concrete dome shown is one of two. The other toppled into a nearby creek bed.

(Picture by W. G. Penney)

FIGURE 104B

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CATHOLIC CHURCH

(Approximately 0.4 Miles Northeast of Zero Point)

View of blast wreckage showing very thick brick walls.

FIGURE 105

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N-7

CATHOLIC CHURCH

(Approximately 0.4 Miles Northeast of Zero Point)

◦ View of wreckage. Note brick walls two feet and more in thickness. Masonry buildings were demolished or badly wrecked by the blast.

FIGURE 106

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N-8

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CATHOLIC CHURCH

(Approximately 0.4 Miles Northeast of Zero Point)

Reinforced concrete dome toppled by the Atomic blast. Note remains of heavy brick walls of church (in background).

FIGURE 107

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N-10

SMALL FACTORY

(Approximately 0.3 Miles Southeast of Zero Point)

The remains of a small factory, probably of masonry construction. Masonry buildings were completely wrecked or seriously damaged by the blast.

FIGURE 108

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N-40

SMALL FACTORY

(Approximately 1.2 Miles South of Zero Point)

The remains of a small factory, just South of Mitsubishi Steel and Arms Works, heavily damaged by blast and fire.

(Picture by W. G. Penney)

FIGURE 108A

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KYUSHU POWER PLANT

(Approximately 1.3 Miles South of Zero Point)

This plant of masonry walls (brick 12" to 18" thick) and structural steel roof was located on the West bank of the Urakami River. Damage from the blast and fire was very severe.

(Picture by W. G. Penney)

FIGURE 108B

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NAGASAKI ATOMIC BOMB DAMAGE

VII. DAMAGE TO WOODEN BUILDINGS.

Practically every wooden building or building with a timber frame within $1\frac{1}{2}$ miles of zero point was either completely destroyed or very seriously damaged and significant damage resulted as far as $2\frac{1}{2}$ to 3 miles from the explosion center. (See Figures 109 to 112e, inclusive, and Figure 115). Nearly all of such buildings collapsed and a very large number were consumed by fire. Many secondary fires were undoubtedly started when such buildings were wrecked, since nearly all of them contained stoves, charcoal braziers, oil lamps, etc. Figures 45, 74, 75, and 86, show the wreckage of wooden buildings. The Nagasaki Medical School and Hospital Group contained 24 wooden structures, all of which were completely destroyed. (See Figures 33A, 33B, and 34 to 36, inclusive). Nearly all of the dwelling units in Nagasaki were of wood construction.

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WOODEN BUILDING WRECKAGE

(Approximately 1/4 Mile West of Zero Point)

The pile of broken and splintered lumber in the foreground is all that remains of the building adjoining a reinforced concrete school building. Note that the wreckage did not burn.

FIGURE 109

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WOODEN BUILDING

o This picture shows frame work of a building being erected after the blast. Note flimsy members tied together with rope. Note damage from blast and fire. Also note U. S. Truck with enlisted personnel viewing bomb damage.

FIGURE 110



N-21

WOODEN BUILDING

(Approximately $1\frac{1}{2}$ Miles Northeast of Zero Point)

Damage from Atomic blast. Natives are salvaging the wreckage and preparing to rebuild.

FIGURE III

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WOODEN BUILDING

(Approximately $1\frac{1}{2}$ Miles Northeast of Zero Point)

View of damage from blast.

FIGURE 112

MITSUBISHI STEEL AND ARMS WORKS

(From 0.3 to 1.2 Miles South of Zero Point)

This is a view of the wreckage of a wooden guard house adjoining reinforced concrete office building approximately 3/4 of a mile South of zero point. Note structural steel frames in background stripped of roof and siding.

FIGURE 112 A

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WOODEN BUILDINGS
(Dwellings)

(Approximately 1.4 Miles South of Zero Point)

These dwellings, in a ravine, were shielded by the steep hills from the full effects of the blast.

(Picture by W. G. Penney)

FIGURE 112 B

WOODEN BUILDINGS

(Approximately 1.9 Miles Southeast of Zero Point)

These buildings, near the Suwa Shrine, though damaged, were protected from the full effects of the blast by the intervening hills. A good example of shielding.

(Picture by W. G. Penney)

FIGURE 112c

WOODEN BUILDING

(Approximately 2.2 Miles South of Zero Point)

View showing roof, window, and wall damage - near Dejima warf.

No shielding here from hills.

(Picture by W. G. Penney)

FIGURE 112 D

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WOODEN BUILDING
(Dwelling)

(Approximately 2.2 Miles South of Zero Point)

View showing roof damage to dwelling - on West bank of
Urakami River.

(Picture by W. G. Penney)

FIGURE 112 E

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NAGASAKI ATOMIC BOMB DAMAGE

VIII. DAMAGE TO REINFORCED CONCRETE AND RIVETED STEEL CHIMNEYS.

A reference to the various photographs depicting damage, shows that although most of the buildings within the effective limit of the blast were totally destroyed or severely damaged, a very large number of chimneys even close to zero point were left standing, apparently uninjured by the concussion. One explanation is that concrete chimneys are approximately cylindrical in shape and consequently offer much less wind resistance than flat surfaces, such as buildings. Another explanation is that since Nagasaki is subject to Pacific typhoons, the more modern chimneys were probably designed to withstand winds of high velocity. It is also very probable that most of the recently constructed chimneys as well as most of the more modern buildings were constructed to withstand the acceleration of rather severe earthquakes. Since the Atomic Bomb was exploded in the air, chimneys relatively close to zero point were subjected more to a downward pressure than to a lateral pressure, consequently, the overturning moment was probably much less than might be anticipated.

Although many chimneys were left standing, a considerable number were destroyed or severely damaged by the blast. Typical examples are shown in pictures, Figures 113 to 121, inclusive.

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PRISON

(Approximately 1/4 Mile Northeast of Zero Point)

Close-up of reinforced concrete chimney showing horizontal crack caused by the blast. Also, note spalling (chipping out) of concrete.

FIGURE 1/3

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PRISON

(Approximately 1/4 Mile Northeast of Zero Point)

○ Close-up of reinforced concrete chimney showing horizontal crack caused by the blast.

FIGURE 114

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NAGASAKI MEDICAL SCHOOL AND HOSPITAL

(From 0.4 to 0.55 Miles Southeast of Zero Point)

Reinforced concrete chimney broken off by the Atomic blast. Note foundations of wooden building destroyed by blast and fire.

FIGURE 115

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NAGASAKI MEDICAL SCHOOL AND HOSPITAL

(From 0.4 to 0.55 Miles Southeast of Zero Point)

Another courtyard, showing steam plant and severely damaged reinforced concrete chimneys in background. Note how chimney on right is inclined off of vertical. Also, note combustible material that did not burn.

FIGURE 116

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SMALL REINFORCED CONCRETE CHIMNEY

(Approximately 1/4 Mile North of Zero Point)

This chimney, part of an industrial plant, was knocked over approximately 15-feet above the base. The chimney was 4.3 feet in diameter and 65-feet high. The wall thickness was 6-inches and the reinforcing consisted of 5/16-inch round bars spaced on 6-1/2-inch centers. The horizontal reinforcing was 1/8-inch round bars with an 8-inch spacing. This chimney was unlined.

FIGURE 117

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SMALL REINFORCED CONCRETE CHIMNEY

(Approximately 1/4 Mile North of Zero Point)

This is a close-up of a small reinforced concrete chimney, part of an industrial plant, which was knocked over by the force of the blast. Diameter at the break was approximately 4.3 feet and the wall thickness was 6-inches. The reinforcing consisted of 5/16-inch round bars, spaced on 6-1/2 inch centers. The horizontal reinforcing consisted of 1/8-inch round bars with 8-inch spacing. The chimney, about 65-feet high, was broken off approximately 15-feet above the base. The quality of the concrete appeared poor. The percentage of reinforcing was only 0.2. American designs generally have 0.8 to 1.0 percent.

FIGURE 118

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REINFORCED CONCRETE CHIMNEY

(Approximately 1/4 Mile North of Zero Point)

This chimney, part of a large brick works, was knocked over by the force of the blast, 19-feet above the ground. The chimney was 7.4 feet in diameter and estimated to be approximately 100-feet high. The wall thickness was 7-1/2-inches at the break. Vertical reinforcing consisted of 1/2-inch round bars on 8-inch centers and 1/2-inch round bars on 16-inch centers. The horizontal reinforcing was 3/16-inches in diameter, with a spacing of 18-inches.

FIGURE 119

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REINFORCED CONCRETE CHIMNEY

(Approximately 1/4 Mile North of Zero Point)

A close-up of chimney, close to the base, on the side facing the blast. Note that concrete has spalled, exposing the reinforcing. The vertical reinforcing consisted of 1/2-inch round bars on 8-inch centers and 1/2-inch round bars on 16-inch centers. Horizontal reinforcing consisted of 3/16-inch round bars with a spacing of 18-inches.

FIGURE 120

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RIVETED STEEL CHIMNEY

(Approximately 0.2 Miles West of Zero Point)

A view of a riveted steel chimney (stack) toppled by the blast. This was the site of a small factory on the West bank of the Urakami River. The chimney was supported on a concrete base and was held in place by six anchor bolts, 1-1/4-inches in diameter. The chimney was approximately 80-feet high and approximately 6-feet in diameter, except for the bottom 4-foot length, which was approximately 8-feet in diameter. The chimney capsized when the anchor bolts failed in tension.

FIGURE 121

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NAGASAKI ATOMIC BOMB DAMAGE

IX. DAMAGE TO BRIDGES.

The bomb blast damaged nearly all of the bridges to some extent, varying from damaged railing to complete destruction of the superstructure. Some of the bridges were wrecked as the spans were shoved off of the piers and abutments by the force of the blast into the river beds below. Others, particularly steel plate girder bridges, were badly buckled by the blast pressure. None of the failures observed could be attributed to inadequate design or structural weakness. Figure 79, and Figures 122 and 123, show details of the destruction of a concrete and steel I-beam bridge 0.3 miles Southwest of zero point. Figures 25 and 80, show only minor damage to bridges relatively close to zero point. Figures 124, 125, and 126, inclusive, show details of damage to another concrete bridge approximately 1/2 mile North of the explosion center. Figures 127 to 131, inclusive, show damage to a steel plate-girder bridge (double track) 0.1 mile Southwest of zero point, while Figures 132 to 136, inclusive, show damage to a single-track steel plate-girder bridge nearby.

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REINFORCED CONCRETE AND STEEL I-BEAM BRIDGE

(Approximately 0.3 Miles Southwest of Zero Point)

Close-up showing completely wrecked superstructure. I-beams could be salvaged for rebuilding the bridge. Piers and abutments were undamaged.

FIGURE 122

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REINFORCED CONCRETE BRIDGE

(Approximately 1/2 Mile North of Zero Point)

This bridge consisted of a reinforced concrete T-beam deck with concrete abutments and piers. The three spans are approximately 35 feet each. Failure of the west span resulted when the deck was knocked off the pier and abutment by the force of the blast from the South, causing the span to drop to the river bed. It can be seen that the remainder of the bridge was not injured except that the pipe hand rail was ripped off by the blast.

FIGURE 124

REINFORCED CONCRETE BRIDGE

(Approximately 1/2 Mile North of Zero Point)

This is an end view showing the details of construction.
Note that deck consisted of four T-beams with reinforced concrete slab.

FIGURE 125

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STEEL THROUGH PLATE GIRDER DOUBLE TRACK RAILWAY BRIDGE

(Approximately 0.1 Mile Southwest of Zero Point)

This view shows the damage wrought by the blast. Note that as the plate girders were moved to the left by the blast, the railroad tracks were bent out of shape and trolley cars were completely demolished. Note that trolley poles were not knocked down by the blast. The building in the background is a reinforced concrete structure which was used for a school (Shiroyama).

FIGURE 127

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STEEL THROUGH PLATE GIRDERS DOUBLE TRACK RAILWAY BRIDGE

(Approximately 0.1 Mile Southwest of Zero Point)

The girders were 40-1/4 inches deep and the span was 37 feet, 4 inches. (Details are given on the attached sketch). The girders were moved a distance of 39 inches on the North end and 60 inches on the South end. Note that the girder was badly buckled by the blast. This bridge had not been repaired two months after the blast. The bridge failure was apparently caused by the pressure of the blast wave against the comparatively large area presented by the plate girder. Inspecting the damage are Colonel S. L. Warren and Captain W. C. Youngs, Jr. The building in the background is the Chinsei Middle School.

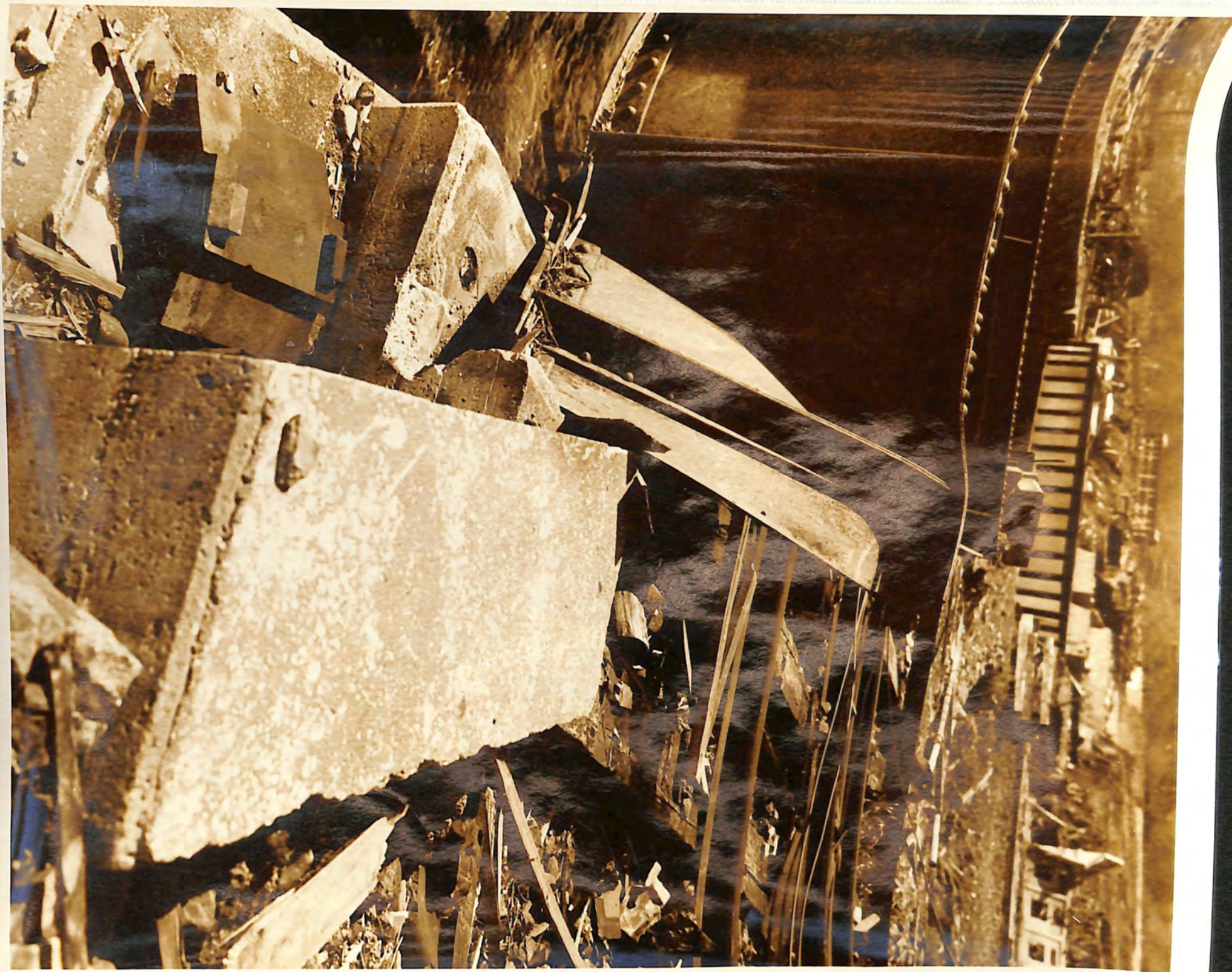
FIGURE 128

STEEL THROUGH PLATE GIRDER DOUBLE TRACK RAILWAY BRIDGE

(Approximately 0.1 Mile Southwest of Zero Point)

This is a close-up of the Northeast corner showing how girder was knocked loose from the metal bridge seat and buckled by the blast. Note the large amount of wood splinters and other combustible material which did not burn.

FIGURE 130



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STEEL THROUGH PLATE GIRDER DOUBLE TRACK RAILWAY BRIDGE

(Approximately 0.1 Miles Southwest of Zero Point)

This is a view looking down on tracks between the girders,
showing buckled X-bracing.

FIGURE 131

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STEEL THROUGH PLATE GIRDER SINGLE TRACK RAILWAY BRIDGE

(Approximately 0.1 Mile Southwest of Zero Point)

This bridge was located across the Urakami River. It was constructed on a 45-degree skew with a 55-foot span and the plate girders were 67-1/4 inches deep. Although this bridge was severely damaged, emergency repairs were made by the Japanese with the use of crosstie shoring and the bridge was thereby made usable a short time after the blast.

FIGURE 132

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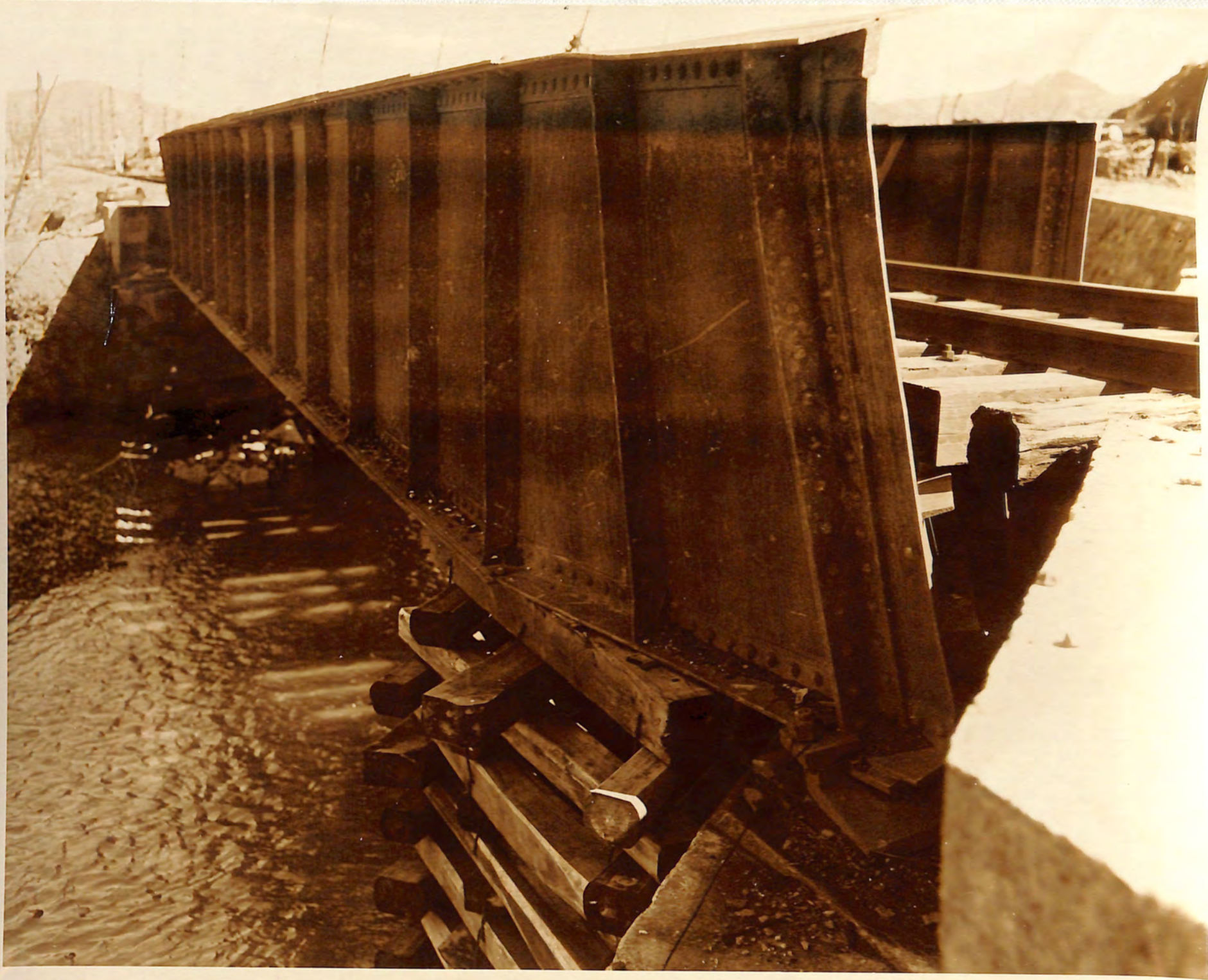
STEEL THROUGH PLATE GIRDER SINGLE TRACK RAILWAY BRIDGE

(Approximately 0.1 Miles Southwest of Zero Point)

This is a close-up at the Southwest corner, showing how the girder was buckled as the end was held firmly on the steel bridge seat. Note crosstie shoring used for temporary repairs.

FIGURE 133

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STEEL THROUGH PLATE GIRDER SINGLE TRACK RAILWAY BRIDGE

(Approximately 0.10 Miles Southwest of Zero Point)

Close-up of the Northeast corner, showing movement of approximately 3-1/2 inches. The south end of this girder (opposite end) was moved approximately 14-1/2 inches.

FIGURE 135

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STEEL THROUGH PLATE GIRDER SINGLE TRACK RAILWAY BRIDGE

(Approximately 0.10 Miles Southwest of Zero Point)

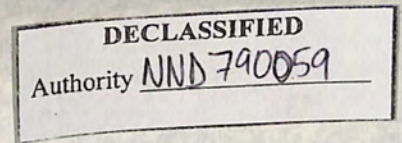
Close-up at the Southeast corner, showing how East girder was moved a distance of approximately $14\frac{1}{2}$ inches. The opposite end (North end) was moved a distance of approximately $3\frac{1}{2}$ inches.

FIGURE 136



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NAGASAKI ATOMIC BOMB DAMAGE

x. DAMAGE TO RAILROADS AND ROADS.

The roads, railroads and the street railways in Nagasaki sustained practically no primary damage as a result of the Atomic Bomb explosion. The only damage to railroads occurred from secondary causes, such as fires and damage to bridges or other structures. Streets were impassable for awhile because of debris, but were not damaged. The fact that the Atomic Bomb was exploded at a considerable distance above ground probably explains the absence of direct damage to railroads and roads. Figures 26, 27, 29, 127 and 139, are views following the explosion.

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NAGASAKI ATOMIC BOMB DAMAGE

XI. DAMAGE TO UTILITIES.

While comparatively little electrical power was generated in Nagasaki, a large part of the electric supply was interrupted by the bomb blast, chiefly through damage to electric substations. Figures 137 and 138, show damage to electric substations supplying power to the Mitsubishi Steel and Arms Works and other industries nearby.

Both the Kyushu Gas Works and the Urakami Gas Works were very severely damaged by the bomb blast. They had not been placed in operation as late as six weeks after the Atomic explosion. Figures 139 to 140a, inclusive, depict damage to the Kyushu Gas Company, the Urakami Gas Works, and the Power Plant, respectively.

In addition to damage sustained by the electric system and the gas works, severe damage to the water supply system was reported by the Nagasaki Municipality. The chief damage was a number of breaks in the 27" cast iron water main supplying the Industrial Valley of Nagasaki. Numerous breaks were also reported in many of the smaller mains and the city was still suffering from a water shortage six weeks later. All of these breaks were attributed by Nagasaki officials to the Atomic Bomb blast.

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ELECTRIC SUBSTATION

(Approximately 0.9 Miles Southwest of Zero Point)

This substation was located on the west bank of the Urakami River opposite the Mitsubishi Steel and Arms Works. The blast bent steel framework and damaged insulators and transformers very severely. The substation had not been put back in operation as late as six weeks after the Atomic blast.

FIGURE 137

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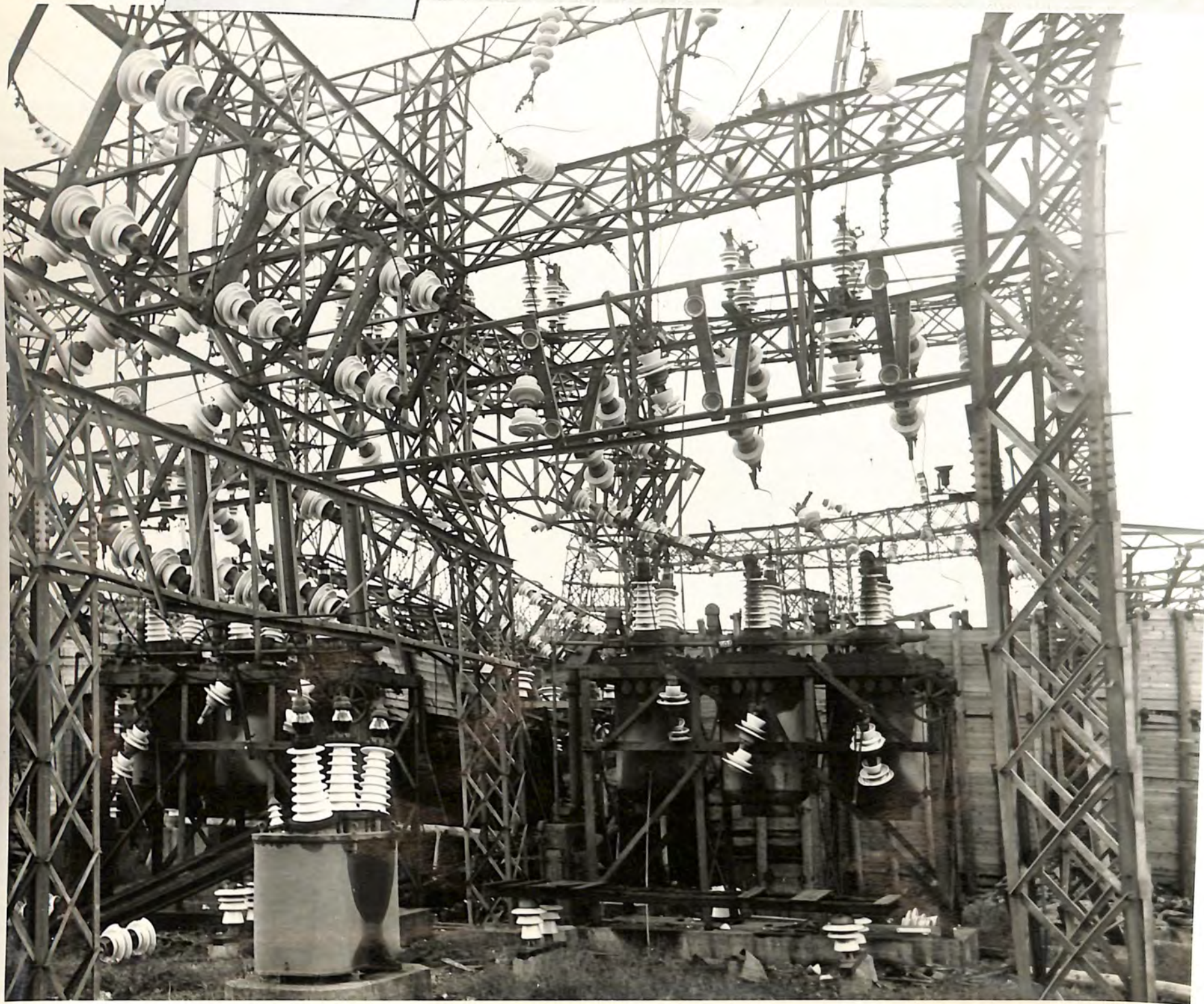
ELECTRIC SUBSTATION

(Approximately 0.9 Miles Southwest of Zero Point)

° Close-up of transformer bank showing damage to structural steel, insulators, etc.

FIGURE 138

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GAS TANKS OF THE KYUSHU GAS COMPANY

(Approximately 1.3 Miles South of Zero Point)

Note that the domes of both tanks have been buckled by the blast, and the plant as a whole is severely damaged. This is a view looking North along the main North-South Street, paralleling the double track street railway. The hills in the right foreground shielded parts of the residential and business section of Nagasaki from the full effects of the blast.

FIGURE 139

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URAKAMI GAS WORKS

(Approximately 0.6 Miles North of Zero Point)

View showing wreckage of gas works and devastation in this vicinity. Wreckage of automobiles is seen in foreground.

FIGURE 140

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POWER PLANT

(Approximately 0.7 Miles North of Zero Point)

This industrial plant of reinforced concrete and masonry was severely damaged by the blast. The concrete chimney apparently was not structurally damaged.

FIGURE 140A

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NAGASAKI ATOMIC BOMB DAMAGE

XII. FIRES.

As pointed out previously, the fires which followed the Atomic explosion were most probably started in two different ways; namely, by the ignition of combustible material directly by the heat of the explosion, and by secondary causes following collapse or serious damage to buildings by the concussion. Also as pointed out previously, the evidence seems to indicate that a large majority of the fires were of secondary origin and not caused directly by the heat from the blast. It appeared that before the blast could start fires by direct heat, conditions had to be quite favorable, that is, thoroughly dry paper, straw or other tinder had to be exposed. Figures 14, 15, 109, 141, etc., illustrate the large amount of combustible material close to zero point which did not catch fire.

A study of numerous aerial photographs prior to the Atomic bombing, indicates that between 10 June and 9 August 1945, the Japanese constructed fire breaks in certain areas of Nagasaki in order to control large scale fires. These breaks are shown in Figure 8. In general they were not effective because fires were started at many locations within a very few minutes. They appear however, to have helped prevent fires from spreading further East into the main business and residential section of Nagasaki. (See Figure 9). Figures 26, 27, 28,

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XII. FIRES. (Continued)

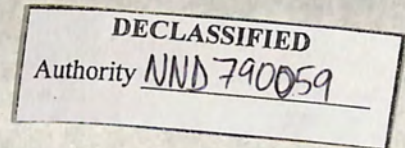
and 30, show the devastation caused by the fires following the wrecking of buildings by the blast. Other pictures showing results of fire are Figures 34, 35, 36, 49, 50, 51, 61, 115, 117, 119, and 120.

Figures 42, 45, 48; Figures 74, 86, and 116, show severe blast damage without the occurrence of fires.

According to the Chief of the Nagasaki Fire Department, his department was unable to do any effective fire fighting following the explosion. The substation, located approximately 1/2 mile North of zero point, was destroyed with a complete loss of all equipment and personnel. Several other substations, located in various parts of Nagasaki, as well as the fire station headquarters, located in the main business section, were unable to operate effectively because of death or injury to part of the personnel or because of damage to fire fighting equipment. The Fire and Police Departments also had to take the lead in organizing rescue and first-aid groups to administer to the survivors. The dozens, and probably hundreds of fires, therefore, spread throughout the Urakami Industrial Valley of Nagasaki practically unchecked. Because of the very large number of wooden buildings and dwellings, there were great quantities of combustible material to feed the fires. Many people who were not killed outright by the bomb con-

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XII. FIRES. (Continued)

concussion, flying missiles, falling timbers or the collapsing of buildings, were burned to death or severely injured by the fires which consumed most of the area affected by the bomb. Even if the Fire Department had not been completely demoralized by destruction of a large part of its equipment and the loss of considerable personnel, the Department would still have been quite ineffective in dealing with the conflagration because of its magnitude and because of a lack of modern fire fighting equipment. Figure 142 is a picture showing typical equipment upon which the Japanese relied. The Fire Department also possessed a large number of hand pumps which were used to supplement the obsolete motor driven fire trucks and the few pieces of modern equipment which they had. It was evident that the over-all damage from fire was practically as great as that caused directly by the blast concussion.

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PRISON

(Approximately 1/4 Mile Northeast of Zero Point)

View showing wreckage of concrete walls. Note water tank on concrete frame left standing. Reinforced concrete chimney standing was damaged by the blast. Note large amount of combustible material that did not ignite.

FIGURE 141

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FIRE ENGINE

This fire engine is typical of a large part of the obsolete equipment the Japanese relied on. They had a limited number of much more modern fire engines.

FIGURE 142

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NAGASAKI ATOMIC BOMB DAMAGE

XIII. CASUALTIES (Relation to Building Types)

As pointed out under "General Description of Damage" the percentage of casualties was very closely related to the distance from zero point and to the degree of exposure, i.e., whether people were in the open or in a substantial building or air raid shelter. It will be noted in the tabulation of casualties that of the total number of recorded deaths as of 20 August 1945, approximately 55% occurred within a radius of 1,000 meters (0.62 miles) and 97% occurred within a radius of 1,500 meters (0.93 miles) from zero point. This indicates very strongly that proximity to zero point is the most important single factor affecting the number of casualties.

The casualties were caused by blast concussion, flying glass and other missiles, falling objects including timbers, suspended ceilings, plaster, walls, roofs, etc., infra-red and ultra violet burns, gamma and neutron radiation, and ordinary fires (of both primary and secondary origin).

People in wooden buildings (principally dwellings) which were seriously damaged by the Atomic explosion received nearly all of the various types of injuries just described, since most of the houses collapsed on the victims and fires consumed the wreckage. The walls were completely ineffective in shielding the occupants from gamma radia-

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XIII. CASUALTIES. (Relation to Building Types) (Continued)

tion and many people therein developed radiation disease in various degrees depending on proximity to zero point. The walls were effective in shielding from infra-red and ultra-violet burns, even close to zero point. People had to be in the open to receive such burns.

Since the many masonry (brick or stone) buildings seriously injured by the blast, principally small factories, churches, etc., generally collapsed, people therein received about the same type of injuries as those in wooden buildings, except that masonry walls provided greater shielding from gamma and neutron radiation.

Many of the buildings with reinforced concrete frames received practically no structural damage and even those with damaged frames did not collapse. Although this tended to reduce fatal injuries, injuries to occupants were nevertheless severe because of flying glass and falling suspended ceilings of wood or metal-lath and plaster. The various types of injuries, therefore, were about the same as those occurring in masonry buildings except that not so many people were crushed. Casualties were smaller in concrete buildings than in any other type and fatal injuries were much smaller.

Structural steel-frame buildings with corrugated metal or corrugated asbestos roofs and siding were used chiefly for large factories

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XIII. CASUALTIES. (Relation to Building Types) (Continued)

such as the Mitsubishi Steel and Arms Works. In such buildings steel frames of light construction were twisted and bent, a few collapsed completely, but the heaviest frames were only slightly damaged by the blast. Injuries to occupants were about the same as those in wooden buildings except that a much smaller percentage of people was fatally crushed and burned.

The Japanese found that air-raid shelters even close to zero point were not seriously damaged. Within a radius of 500 meters (0.31 mile) "....., no outdoor shelters (with covers) or even extremely imperfect air-raid trenches which were dug into the ground horizontally were ruined". Within a radius of 1,000 meters (0.62 miles), "the semi-underground air-raid shelters..... showed no change inside or outside. The hillside-trench shelters with the simple explosion wind-breakers were undamaged". At 2,000 meters (1.25 miles), "hillside-trench air-raid shelters were completely intact". These so-called hillside trenches were generally small caves of trench-width dug horizontally into the sides of hills or bluffs and usually provided with a door or explosion wind-breaker. While many of the wind-breakers were broken close to zero point, those beyond 1,000 meters (0.62 mile) were not seriously damaged and people in all such air raid shelters generally were completely protected or received only minor injuries. Unfortunately

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XIII. CASUALTIES. (Relation to Building Types) (Continued)

for the Japanese very few people had taken refuge in air-raid shelters when the Atomic explosion occurred.

Occupants of all types of buildings, unless they were in front of windows or open doors, were shielded from burns by ultra-violet and infra-red radiation. While people in the open at a distance of 1.8 miles from zero point received burns on exposed skin, effective shielding was provided by one thickness of ordinary clothing.

Shielding from lethal amounts of gamma and neutron radiation was effected by ceilings and walls of reinforced concrete 6 to 7 inches thick at a distance of $3/4$ of a mile from zero point while people in adjoining buildings with corrugated metal or asbestos roofs and siding were injured by radiation. Walls and ceilings of concrete 4" thick provided effective shielding at a distance of 1.1 miles from zero point. Figures 69, 88, and 89, depict examples of shielding from radio-active rays.

To summarize, casualties of all types resulting from the Atomic Bomb (particularly fatalities), were many times (possibly ten to fifteen times) greater than would have been expected from a comparable amount of physical damage inflicted by bombing with ordinary high explosive or in-

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XIII. CASUALTIES. (Relation to Building Types) (Continued)

cendiary bombs. It is indicated that total casualties resulting from an Atomic explosion over a large American City, would be of the same order as those caused by the Atomic Bombs at Hiroshima and Nagasaki.

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NAGASAKI ATOMIC BOMB DAMAGE

XIV. CONSTRUCTION TO WITHSTAND ATOMIC EXPLOSIONS.

As pointed out previously in this report (General Description of Damage), none of the buildings at Nagasaki relatively close to zero point withstood the Atomic explosion successfully. Buildings of wood, masonry, and light steel or concrete were completely wrecked or very severely damaged and over-all damage and casualties were also severe in buildings with heavy structural steel or reinforced concrete frames even though such buildings did not collapse. Also, as pointed out, to withstand an explosion successfully, a building must be able to withstand the pressure developed and to protect equipment from damage and occupants from all types of injuries. This would require heavily constructed buildings of steel and/or concrete without windows, and such buildings would have to be air-conditioned and artificially lighted.

The fact that damage to building interiors and contents was severe and casualties were numerous in even the strongest reinforced concrete buildings, shows that damage and casualties would likewise be severe in a large modern American City such as New York, Chicago, or Detroit, following an Atomic explosion. Many buildings would not be demolished, but heavy damage and many casualties would nevertheless occur as described herein.

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Apparently no data on pressure - time relationships were obtained, hence very little is actually known about the duration of the Atomic blast. Massive structures because of their relatively great inertia could absorb the dynamic shock of a large concussion if of extremely short duration, i.e., the pressure would subside before very much stress could be induced into the structure. The duration of the concussion wave is believed to be appreciable greater, however, than for ordinary high-explosive bombs and the pressures are known to have persisted sufficiently long in many instances at Nagasaki to stress ordinary concrete panels, beams, columns, structural steel frames and other structures to failure. Although probably quite conservative, the peak hydrostatic pressures (100% of the values) as calculated by Dr. W. G. Penney, British Physicist, were therefore used for design pressures as equivalent uniform static loads after adding an arbitrary allowance of 50% for impact.

It is not known what pressures a building close to zero point would have to withstand. At Hiroshima the maximum pressure was determined by Dr. Penney, to be approximately 35 pounds per square inch. He estimated that the maximum pressure at Nagasaki was of the order of about 150 to 200 pounds per square inch on the ground at zero point. Future Atomic ex-

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plosions may develop even greater pressures, but to determine a satisfactory building design close to the blast center (assuming bomb to be exploded 1,500 to 2,000 feet above the target) a pressure of 250 pounds per square inch (plus 50% impact) was used as the effective design pressure. Because of the tremendous pressures developed in the actual explosion center, it would not be feasible to design a building to withstand a direct hit.

Because of the relatively short duration of stresses resulting from an Atomic blast concussion it should, theoretically be possible to increase ordinary allowable working stresses considerably, particularly allowable shearing stresses (diagonal tension) in concrete which are set at very conservative values to prevent even the smallest of shear cracks. In the concrete designs which follow, therefore, the working stresses for shear were doubled and those for compression in extreme fiber were increased 50% in relation to values ordinarily used. In the steel designs, working stresses for shear and for bending were increased 50% above the values recommended by the American Institute of Steel Construction.

The reinforced concrete and structural steel designs which are presented in this section are not complete analyses of all of the various

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members making up a building. The approximate sizes of beams, columns, slabs, etc., as shown, are given to indicate roughly the order of dimensions of some of the more important members to withstand the loads as set forth. The accuracy of the designs are, of course, limited by the accuracy of the assumptions on which they were based, i.e., blast pressures, impact, working stresses, etc. Results are also affected by the interrelation which exists between the duration of the peak pressures and the inertia of the massive members. This interrelationship was considered only indirectly in the design assumptions. It should also be noted that depths of beams in relation to spans, in most instances are very great - much greater than in ordinary designs - with the result that some arch action is probably introduced. No adjustments, in sizes of members, however, were made for arch action. Notwithstanding the design assumptions as indicated, and the lack of more complete information on blast pressures, the sizes of members as shown, are believed to be sufficiently accurate to present a general indication of (Structural) requirements.

The thickness of walls, sizes of columns and beams to withstand a uniform loading of 250 pounds per square inch (36,000 pounds per square foot) depends upon ceiling height, and spacing of members in addition to impact allowance and working stresses. A ceiling height of 8 to 9 feet

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XIV. CONSTRUCTION TO WITHSTAND ATOMIC EXPLOSIONS. (Continued)

(net) was selected for economy. Wall columns, which must also act as vertical beams, were spaced on 10 foot centers. It is obvious that the lower the ceiling and the closer the spacing of columns and beams the lesser will be the wall and ceiling thickness, and the smaller the size of beams and columns. It is also obvious that a building with closely spaced interior columns has (in most cases) less utility than one with columns at wider intervals or one without interior columns.

In designing a reinforced concrete building, only a few calculations were necessary to show that ordinary over-all ceiling heights were unsatisfactory because the required depth of ceiling beams were over 7 feet, leaving practically no overhead clearance, even with columns spaced on 10-foot centers. It was found necessary to use an over-all ceiling height of 16 to 17 feet in order to have a net height (clearance) of at least 8 feet. Because of the great depths of beams and slabs in relation to the spans, the sizes of members, in many cases, were controlled by the resistance to shear rather than resistance to bending.

The following design gives approximate dimensions of some of the more important members of a one-story reinforced concrete building to withstand a loading of 36,000 pounds per square foot (plus impact) for the criteria indicated.

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Column Spacing.....10 Ft. - Center to Center

Roof Slab.....10 Ft. x 10 Ft. Panels (span, center to
center of beams)
Simply Supported.....Thickness.....41"
Complete Restraint.....Thickness.....39"

Roof Slab.....5 Ft. x 5 Ft. Panels (Span-center to
center of beams)
Simply Supported.....Thickness.....22"
Complete Restraint.....Thickness.....20"

Ceiling Height (Over-all).....17 Ft.

Roof Beams.....10 Ft. Span (Center to center of supports)
Simply Supported.....10 Ft. by 10 Ft. panels
Beam.....45" x 99"
Four - 5 Ft. x 5 Ft. Panels
Beam.....45" x 99"
Secondary (5 Ft. x 5 Ft. panels).....Beam.....35" x 66"

Roof Beams.....10 Ft. span (Center to center of Supports)
Complete Restraint:
10 Ft. by 10 Ft. Panels.....Beam.....45" x 99"
Four - 5 Ft. x 5 Ft. Panels....Beam.....45" x 99"
Secondary Beam.....5 Ft. x 5 Ft. Panels.....35" x 66"

Net Ceiling Height (10 Ft. Panels).....8 Ft. - 9 In.

Net Ceiling Height (5 Ft. Panels).....8 Ft. - 9 In.

Wall Columns (Vertical Beams) Two - 8.5 Ft. by 10 Ft. Panels
Simply Supported.....(10 Ft. spacing - 17 Foot span)- 83" x 138"
Complete Restraint - (10 Ft. spacing - 17 Foot span)- 83" x 138"

(Note wall columns should project outside of wall slabs to prevent sacrifice of room space, although it would present an unusual appearance).

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Horizontal wall beams, connecting wall columns at midpoints,
making two - $8\frac{1}{2}$ Ft. x 10 Ft. panels.

Simply Supported:

Span center to center of columns (10 Ft.) Beam.....55" x 95"

Complete Restraint:

Span center to center of columns (10 Ft.) Beam.....55" x 95"

Wall Slab ($8\frac{1}{2}$ Ft. by 10 Ft. panels)

Simply Supported - Span center to center of beams
Thickness.....43"

Complete Restraint - Span-center to center of beams
Thickness.....43"

Interior Columns - 10 Ft. center to center.....57" x 57"

(Because of the large size and close spacing of columns there would not be sufficient usable space (only 73" clear between columns). Additional usable space can be obtained by resorting to structural steel columns each consisting of a 14" wide flange, 320-pound, column core with two-24" x $3\frac{5}{8}$ " plates and two-24" x $1\frac{1}{2}$ " plates. This would provide 8-feet, clear between columns).

The foregoing example is an approximate design of members to withstand bending, shears, and compression. Members will probably require modification to resist distributed fixed-end moments and shears. Many members could be somewhat reduced in size by the use of double-reinforced beams and slabs, i.e., use of reinforcing in compression side and extra

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steel in tension side and by T-beam designs. Where the blast wave hits one side of the building the lateral thrust can be taken either by a rigid-frame construction or by buttress columns (at say 45 degrees) outside of the building or by a combination of the two. For multiple story buildings all of the thrust above the first floor would have to be resisted by the rigid frame.

The foregoing building designs, with columns spaced 10 feet on centers, would be satisfactory for some uses, but for others such a close column spacing would be very objectionable. The use of an appreciably greater column spacing, however, increases the size of members so rapidly that the volume of unusable space in the building would soon equal or exceed the volume of usable space. The following example illustrates this fact:

One-Story Building: (Reinforced Concrete)

Column Spacing.....20 Ft. center to center

Roof.....Four - 10 Ft. x 10 Ft. panels

Main Roof Beams (20 Ft. span)

Simply Supported.....101" x 175"

Complete Restraint.....101" x 175"

Required over-all ceiling height for net clearance of at least 8 feet is therefore 22.6 Ft. Thus 14.6/22.6, which is equivalent to 64.7% of the building volume is unusable space. Such a design is very uneconomical.

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It is possible to use even greater column spacings, but the amount of usable space in the building would rapidly drop to a relatively small percentage of the total volume of the building.

If structural steel is used instead of reinforced concrete the following one-story building design (approximate) to withstand 36,000 pounds per square foot plus 50% impact, is obtained:

Column Spacing 10 Ft.....Center to Center

Roof Slab (Plate).....10 Ft. x 10 Ft. Panels (Span-center
to center of beams)

Simply Supported.....Thickness of Plate.....8.5"

Complete Restraint.....Thickness of Plate.....7"

Roof Slab (Plate).....5 Ft. x 5 Ft. Panels

Simply Supported.....Thickness of Plate.....4.5"

Complete Restraint.....Thickness of Plate.....3.5"

Ceiling Height - Over-all.....13.5 Ft.

Roof Beams (10 Ft. span) - Primary

10 Ft. x 10 Ft. panels - beams.....Use 60" plate girder consisting of 60" x 1-1/4" vertical plate with four-8" x 8" x 1/2" angles.

Add stiffeners as required.

Four - 5 Ft. x 5 Ft. panels - beam.....Use 60" plate girder consisting of one - 60" x 1-1/4" vertical plate with four - 8" x 8" x 1/2" angles and two - 17" x 3/4" plates. Add stiffeners as required.

Net Ceiling Height(10 Ft. panels).....8 Ft. - 6 In.

Net Ceiling Height (5 Ft. Panels).....8 Ft. - 4 1/2 In.

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Wall Columns (Vertical Beams)

10 Ft. Spacing.....13.5 Ft. span.....Use 60" plate girder consisting of one 60" x 3" plate with four 8" x 8" x 1-1/8" angles and two - 18" x 1" plates. Add stiffeners as required and additional members (angles or channels) as necessary for compression in columns.

Wall Slab (Plate).....10 Ft. x 13.5 Ft. Panels
Simply Supported.....Thickness.....11"
Complete Restraint.....Thickness.....9"

Wall Slab (Plate).....5 Ft. x 6.75 Ft. Panels
Simply Supported.....Thickness.....5.5"
Complete Restraint.....Thickness.....4.5"

Interior Columns.....10 Ft. Centers.....Use 14" wide flange, 320-pound column core with two-24" x 3-5/8" plates and two-24" x 1 1/2" plates.

The foregoing structural steel design should be modified as required to resist distributed fixed-end shears and moments as indicated for the reinforced concrete design.

A more practical design would be to use a structural steel frame and reinforced concrete roof and wall slabs, with members and slab thicknesses as previously indicated. It is obvious from the foregoing that any design to withstand 250-pound per square inch (plus impact) would be extremely expensive.

Special designs, such as a building in the shape of a hemisphere, should prove more economical than conventional shapes, but much waste space

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would occur, nevertheless, because of the odd shapes. Another solution would be to build underground structures, but in most cases this would also be very costly.

Inasmuch as the cost of structures designed to withstand blast pressures of the order of 250-pounds per square inch (36,000 pounds per square foot) would be extremely great and since blast pressures diminish rapidly with relation to distance from zero point, it would probably be economically advisable except in the case of critically important installations to design for pressures to be expected at some distance, say about 1/2 mile from zero point, and to anticipate failure or partial failure of structures within the selected distance. In the case of the Nagasaki Bomb, the design might be based roughly on a pressure of 3,000 pounds per square foot (slightly less than 21-pounds per square inch). The following is an approximate design to withstand this pressure for the criteria as indicated:

Reinforced Concrete One-Story Structure: (Impact Allowance: 50%)

Column Spacing.....10 Ft. Center to Center.

Roof Slab.....10 Ft. x 10 Ft. Panels (span - Center to center of beams)

Simply Supported.....Thickness.....13.5"

Complete Restraint.....Thickness.....11.5"

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Roof Slab.....5 Ft. x 5 Ft. Panels (Span - center to center
of beams)
Simply Supported.....Thickness.....8 Inches
Complete Restraint.....Thickness.....7 Inches

Ceiling Height - Over-all.....12.0 Feet

Roof Beams.....10 Ft. Span
10 Ft. x 10 Ft. Panels.....Beam.....18" x 34"
Four - 5 Ft. x 5 Ft. Panels.....Beam.....21" x 38"

Net Ceiling Height (10 Ft. Panels).....9 Ft. - 2 In.

Net Ceiling Height (5 Ft. Panels).....8 Ft. - 10 In.

Wall Columns (Vertical Beams)
10 Ft. x 12 Ft. Panels - 12 Ft. Span.....Beam.....21" x 41"
Four - 5 Ft. x 6 Ft. Panels.....Beam.....21" x 41"

Wall Slab.....10 Ft. x 12 Ft. Panels (Simply Supported)
Span - center to center of beams.....Thickness.....15.5"

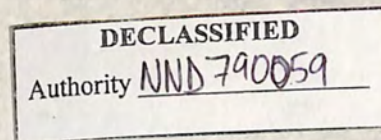
Wall Slab.....Four - 5 Ft. x 6 Ft. Panels (Simply Supported)
Span - Center to center of beams.....Thickness.....9"

Interior Columns
10 Ft. Center to Center.....25" x 25"

This approximate design should be modified as required for fixed-end moments and shears, double reinforcing, etc., as previously stated. While very much lighter than the ones to resist a pressure of 250-pounds per square inch, this design is still heavier than used for ordinary buildings and costs would, consequently be much greater. Unless a frame-work of beams on about 5 to 6 foot centers (very close spacing) each way is used, wall and ceiling slabs would have to be 11.5 inches to 15.5 inches thick as shown (depending

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XIV. CONSTRUCTION TO WITHSTAND ATOMIC EXPLOSIONS. (Continued)

on construction), With the 5 foot spacing, the thickness of slabs, could be reduced to 7" to 9" which is not much greater than ordinarily used in buildings, but even then the cost would be much greater than conventional buildings because of the framework of closely spaced heavy beams. It should also be kept in mind that such designs are subject to partial or complete failure when closer than about 1/2 mile from zero point.

To summarize, it would be practically impossible to construct buildings of commercial size to withstand a direct hit from an Atomic Bomb. It would be physically possible to construct a usable building (designs given herein) to successfully withstand an Atomic explosion at zero point (250 pounds per square inch) when the bomb is detonated 1,500 to 2,000 feet above ground, but the cost of such construction would be extremely great. A compromise structure to withstand blast pressures at about 1/2 mile distance (about 21-pounds per square inch) from zero point would be much less costly and much more feasible, but would still cost a great deal more than conventional buildings. The cost of housing an entire city in such heavy structures (even for 21-pound pressure) would be prohibitive. While no satisfactory solution exists, the most feasible one (assuming the use of Atomic Bombs cannot be prevented) would be to house extremely important installations in massive structures of adequate strength (above or below

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ground) and to disperse all other buildings, dwellings, factories, etc., over as wide an area as possible so that a given Atomic explosion would cause much less damage and fewer casualties. Data from Nagasaki indicate that air-raid shelters underground were very effective in protecting people from serious injury, but unless the population can be warned in time to take shelter the construction of such shelters would be of only limited value. Sufficient warning can be given where Atomic Bombs are delivered by plane, but if delivery should be made by high speed rockets from great distances insufficient warning time would be afforded.

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March, 1946.

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