"*RED BOOKS*" *of the*
*BRITISH FIRE PREVENTION COMMITTEE — No. 214.*
*Edited by the Executive.*

# FIRE

in a

# REINFORCED CONCRETE WAREHOUSE

at

## FAR ROCKAWAY, NEW YORK, U.S.A.


By

IRA H. WOOLSON

(Late Columbia University, New York).




REISSUED IN GREAT BRITAIN BY COURTESY OF THE AUTHOR AND THE NAT. BOARD OF UNDERWRITERS.


LONDON, 1918.

PUBLISHED AT THE OFFICES OF
THE BRITISH FIRE PREVENTION COMMITTEE
*(Founded [illegible]—Incorporated [illegible])*
8 WATERLOO PLACE, PALL MALL, S.W.1.

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# FIRE
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# Reinforced Concrete Warehouse
at
## FAR ROCKAWAY, NEW YORK, U.S.A.
(*10th November, 1916*).

Being a Report prepared for The National Board of Underwriters, U.S.A.

by

IRA H. WOOLSON
(late Columbia University, New York).



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*TWO SHILLINGS AND SIXPENCE*


*Fig.* 1.—View of south and west (rear) sides of the concrete building. The frame wood-working factory was attached to the south side. Note cracks in west wall, and parapet, also fused wired glass windows in south wall, and spalled concrete. The missing fire door was removed after the fire.

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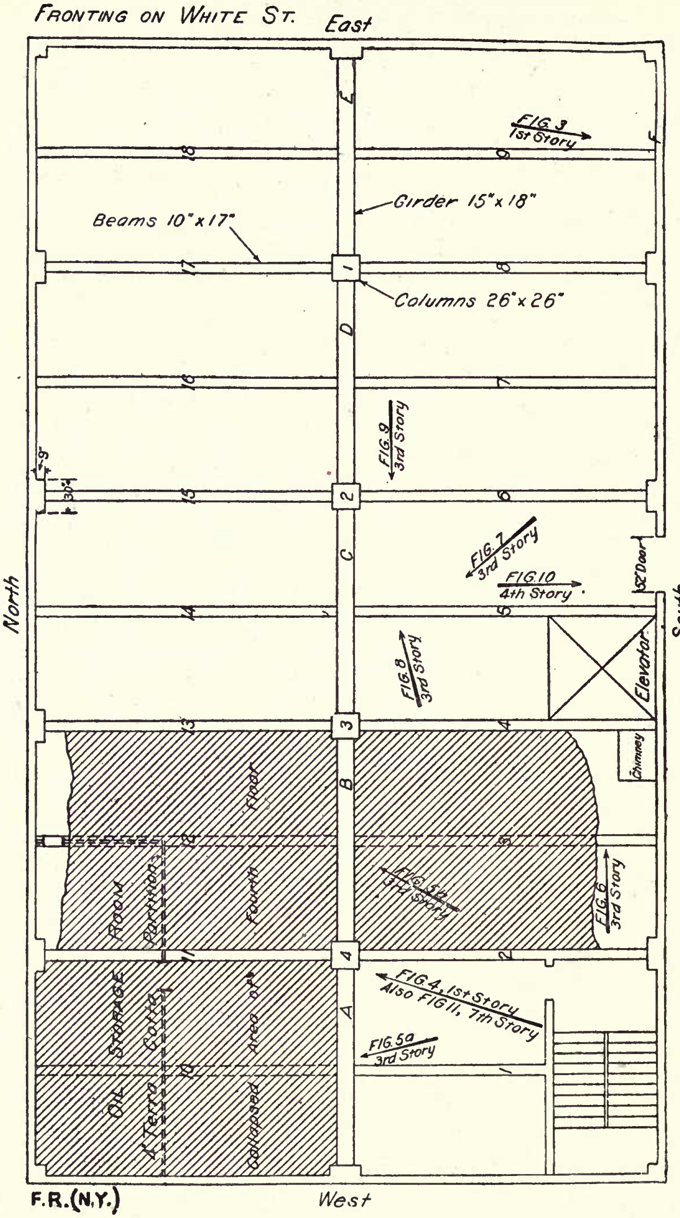


*Fig.* 2.—Plan of third story. All stories had the same general arrangement. Shaded area shows collapse of fourth floor. Large arrows indicate positions where photographs were taken. Beam and girder sizes are measured exclusive of floor slab.

## NOTE.

The Committee are indebted to the kindness of Professor Ira H. Woolson and the National Board of Fire Underwriters, U.S.A., for this interesting report of the fire at a reinforced concrete building at Far Rockaway, New York.

Our knowledge of the behaviour of reinforced concrete under fire conditions is gradually extending as reports come to hand from time to time, and it is interesting to observe that the same general features of damage obtain in each successive report, viz. the spalling of concrete, the exposure of the reinforcement in both columns and beams, and the collapse of some of the panels.

The conclusion one is tempted to arrive at is that the aggregate is alone at fault, although the section of the reinforcement with insufficient spacing may also be responsible.

The aggregate used in the building under review was quartz gravel, and a glance at the illustrations will be sufficient to show to what a serious extent the building was damaged by a fire that was not of excessive temperature or duration. In fact, the building will require extensive reconstruction and repair before it is again available for use.

It is also to be noted that the unequal expansion of the concrete frame in those parts of the building where the heat was greatest is responsible for horizontal and vertical cracks.

Owners of property are often led to believe that where reinforced concrete construction is used the damage in case of fire will be very limited, and there is all too great a tendency to generalize when speaking of this form of construction. Unfortunately, however, reinforced concrete, if of unsuitable material from the fire point of view whilst offering a higher degree of fire resistance than some of the older forms of construction, often requires the expenditure of a large sum in "taking down" in addition to the ordinary cost of reconstruction. This is unsatisfactory and affects the economic value of reinforced concrete.

Unless some more suitable fire-resisting aggregates are adopted or a protective covering devised where unsuitable ones are used, reinforced concrete may be discredited. This would be regrettable seeing this new form of construction is at the present time invaluable when properly designed and applied.

ELLIS MARSLAND.

*Offices of the British Fire Prevention Committee,*
8 *Waterloo Place, Pall Mall,*
*London, S.W.* 1.

*January*, 1918.

P.S.—Having regard to the term "trap" being frequently used as a description of a concrete aggregate met with in the United States, a Memorandum has been added to this report describing this type of aggregate.

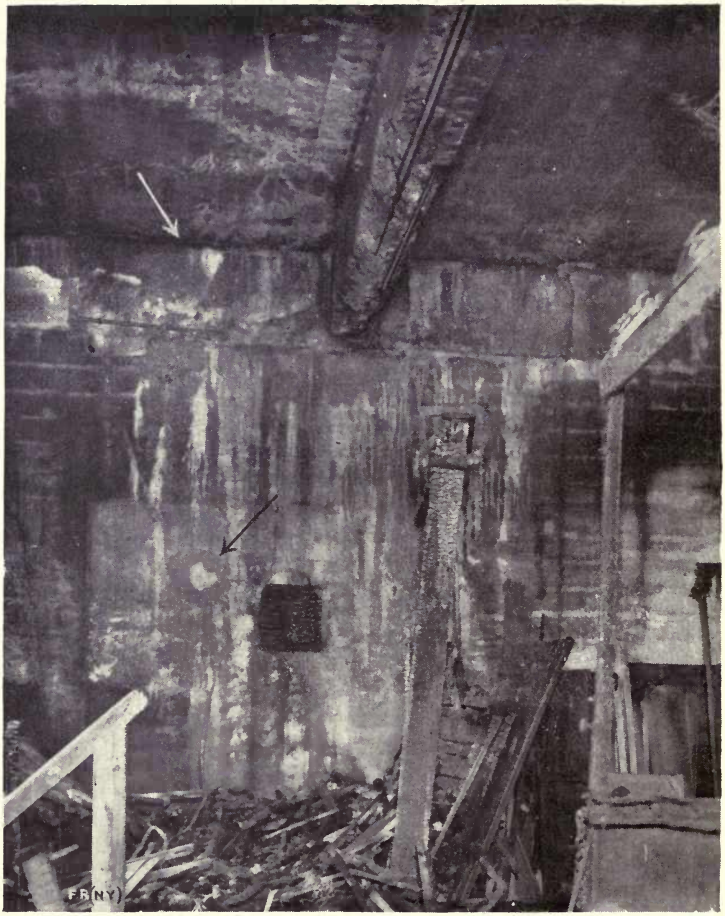


*Fig.* 3.—Location of small fire in south-east corner of first story. Black arrow points to hole in wall where fire entered. White arrow indicates location of hole in floor which transmitted fire to second story. Note unburned material and spalled concrete.

# A FIRE

IN A

# REINFORCED CONCRETE WAREHOUSE

AT

# FAR ROCKAWAY, LONG ISLAND, N.Y., U.S.A.

BEING A REPORT PREPARED BY

**IRA H. WOOLSON.**

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On November 10th, 1916, a fire occurred at Far Rockaway, Long Island, N.Y., U.S.A., which although it caused no loss of life nor any excessive property loss, nevertheless produced results having particular significance to Insurance Underwriters, and therefore justifies a specific report. The feature of this fire which seemed to merit this individual attention was the character and extent of damage sustained by a reinforced concrete building.

The effects produced on this building are more significant than any which have come to the writer's attention since the famous fire in the Edison factories in 1914.*

If the destruction which occurred in this building is indicative of what is liable to happen in any reinforced concrete building of similar construction and under the same general conditions, it is a matter warranting serious consideration by the underwriters who assume the risk.

The fire involved a three-story frame woodworking shop, adjoining a seven-story reinforced concrete building used for furniture storage and repair, as well as some light manufacturing, such as making of screen doors and similar articles. The report is confined to the effects in the concrete building, and the conclusions to be derived therefrom.

No attempt is made to describe the progress of the fire or the methods of fighting it, nor is attention given to the burning of the frame factory. None of these subjects have any particular bearing upon this investigation. Suffice it to say that the fire started from unknown cause about midnight in the frame woodworking factory, and the building was well on fire when discovered. The fire spread rapidly, and four alarms were rung in within a period of 10 minutes after discovery. By this time the frame structure was fully involved; a nearby wooden dwelling on the south side was burning; fire had entered the concrete warehouse; and falling sparks were seriously endangering frame dwellings across the street by igniting the wooden shingle roofs.

* *See B.F.P.C. "Red Book" Nos.* 204 *and* 207.

The woodworking factory was completely destroyed ; the concrete building suffered very serious structural damage ; a large proportion of its contents were ruined ; and several wooden dwellings were badly damaged..

The Fire Department seems to have handled the fire efficiently, considering the distance the apparatus had to travel and other adverse conditions. The fact that fire entered five of the seven stories of the concrete building, and that only a small part of the highly combustible contents were actually burned, testifies to skilful work in the building.

The fire gained entrance to this building by various channels, which will be described in discussing the destruction in each story, though they have no special bearing upon the main purpose of the report.

## DESCRIPTION OF THE BUILDINGS.

The concrete building was a seven-story and basement storage warehouse, owned and operated by Mullen & Buckley, dealers in furniture and house furnishings. It was 52 x 90 ft. in plan. It faced to the east on White Street, but extended through the block, having an entrance adjoining a railway freight track in the rear.

The building was erected in 1909 and was supposed to be a first-class fireproof structure. It was freely advertised as such.

*Fig.* 1 gives a general view of the building from the rear. The only connections between stories were one concrete stairway and one freight elevator shaft. Both of these had 6 in. terra-cotta enclosure walls, with openings in each story protected by approved fire doors. There was nothing to burn in either shaft, and the fire was not transmitted by them. Some of the doors on the elevator shaft were submitted to rather severe punishment, but they appear to have fulfilled their function properly. There was also a horse runway against the rear wall in the first story with open connection to a stable which occupied part of the second story, but neither of these were involved in the fire, although nine horses were smothered by smoke.

The three-story frame woodworking factory was attached to the south side of the concrete building. It was 50 ft. wide and extended the full length of the larger building, as can be seen by inspection of *Fig.* 1 (page 2). The only service communication between the buildings was one doorway in each story, each being protected by two approved fire doors—a sliding door on the exterior of the concrete wall, and a swinging door on the interior. Fire probably passed through one and possibly two of these doorways.

All the windows were wired glass in metal sash and frames ; there is no evidence that fire travelled upwards by way of the windows. The windows above the roof of the frame building had been closed on the inside by 8 in. brick walls built in front of the windows, and overlapping the openings about 8 ins.

## CONSTRUCTION OF CONCRETE BUILDING.

The concrete building was of girder and beam construction, with one row of square columns lengthwise through the middle. *Fig.* 2 is a plan of the third story and is typical of all stories.

The structural design was furnished by the Trussed Concrete Steel Company, U.S.A., but the building was erected by the Industrial Engineering Company. The coarse aggregate was quartz gravel, mostly of a size that would pass an inch screen, but pebbles 2½ in. and larger are frequently seen in all structural parts. It looks as if "run of bank gravel" may have been used. A mixture of one cement, two sand, and four stone was specified. The actual mixture used is unknown. No tests have been made of the concrete, but inspection does not indicate that it was of inferior quality. The building was designed for loads of 120 lb. per square foot on all floors.

***Columns.***—The columns were 31 × 31 in. in the basement, and decreased gradually upwards to 14 × 14 in. in the top story. They were spaced upon 17½ ft. centers.

The third story columns—where a failure occurred—were 26 in. square and reinforced by eight $\frac{11}{16}$ in. ribbed bars, tied at intervals of one foot by ¼ in. round rods having lapped ends, and attached to the vertical rods by light wire wrapping at the crossings. The rods were equally spaced around the columns, and the concrete protection varied from 1½ to 3 in. There was no opportunity to determine column reinforcement in other stories.

***Girders.***—The girders connecting the columns in the third story were 15 in. wide and 18 in. deep below the floor slab, which was slightly in excess of the design requirements. In the third story the free span was 15 ft. 4 in. They were reinforced in the bottom by three "Kahn" trussed bars. The irregular cross-section of these bars measured 1¾ × 2¾ in. The design specified two ¾ in. ribbed bars to be placed above the trussed bars. The ribbed bars to have one end bent up and to extend through into the adjoining girder, having a hooked end for anchorage. Both bars to be hooked where they entered the pilaster column at the wall. So far as can be observed, these requirements were followed, but the ribbed bars were not properly spaced above the trussed bars. In both girders and beams they sometimes touch, and often are not more than ½ in. apart. The trussed bars were protected by ½ to 1½ in. of concrete on bottom and sides.

***Beams.***—The beams were 10 in. wide and 17 in. deep below the floor slab. Every alternate beam had one end resting upon an interior column and the other end upon a pilaster wall column. The others were supported at the middle of interior and wall girders. *Fig.* 2 shows the arrangement of girders and beams for all floors. The free span of beams supported by columns in the third story was 23 ft. 7 in., and for those supported by girders, 24 ft. 7 in.

The beam reinforcement consists of two 1¾ × 2¾ in. "Kahn" trussed bars in the bottom, and above there were two ⅞ in. ribbed bars. The trussed bars were straight and projected about 5 or 6 in. into the girders. One of the ribbed bars at the interior end of the beam was straight and the other bent up near the end, and extended through the interior supporting girder a foot or more into the opposite beam and anchored with a hook. Both bars were bent up and hooked where they entered the wall columns or girders.

The design drawings indicate that the bent up rods, acting as negative reinforcement, should be located near the top of the floor slab, but in the beams which failed they were found in the plane of the bottom of the floor slab. This was probably detrimental. (*See Fig.* 5, p. 24.)

The concrete protection was practically the same as in the girders, varying from ½ to 1½ in. on the bottom and sides.

***Floor Slabs.***—The floor slabs proper varied from 4 to 6 in. in thickness, and upon these a surface finish 1½ to 2 in. thick was cast after the slabs had hardened. This caused the surfacing to break up when a floor deflected.

The reinforcement was expanded rib metal with 4 in. mesh.

The sheets were 32 in. wide and laid at right angles to the beams, with a space of 2 to 4 in. between each sheet. The sheets were cut square at the ends and projected about 4 in. into the beams. There was evidently little attempt to provide proper protection for this metal since it varied from nothing to 1½ in., but was mostly ⅛ to ¼ in. One ⅜ in. square negative reinforcement bar was provided for each sheet of metal. These bars were laid across the beams and extended 12 to 16 in. on top of the rib mesh metal to which they were wired. This placed them very close to the under side of the slabs. In some cases they were omitted, and occasionally there were two bars to a sheet of the reinforcement. *Figs.* 3 to 9 show the appearance of slab reinforcement in the places were collapses occurred. Its close proximity to the surface is plainly visible.

***Walls.***—The wall panels were generally 8 in. thick, though a 6 in. panel was found on the south side. Further details of the construction are omitted, since they are not pertinent to the purpose of this report.

## RESULTS OF THE FIRE.

***Basement.***—The basement was used mostly for storage of lumber, and was not involved in the fire.

***First Story.***—This was the shipping department, and a loading platform extended the full length of the building on the south side. The balance of the floor was devoted to delivery wagon purposes. A quantity of camp chairs and other furniture was stacked up on the platform in a space about 10 × 15 ft. in the south-east corner. A fire occurred here, undoubtedly started by heat coming through a 5 in. hole in the wall through which a home-made sheet metal tube had passed from the upper story of the frame building, being used as a shipping bill carrier system connecting with a receiving station located in this corner. (*See Fig. 3.*)

There was evidently a sharp, short fire here, for bits of copper wire and some thin brass were found melted, indicating a probable maximum temperature of 1,600° to 2,000° Fahr. However, the fire was confined to the small space mentioned and only partially consumed the material piled there.

The photograph is evidence of the smallness of this fire, and yet it will be noted that the wall girder is badly spalled. Chunks of concrete 8 and 10 in. thick fell from the girder, and the reinforcing bars in the bottom of the beam were exposed to 15 ft. The bars had only 1 to 1¼ in. protection.

Almost directly over this hole in the wall there was a 4 in. hole in the concrete floor above it which without doubt served to convey the fire to the second story. This second hole had been left after removal of a steam heating pipe. It is an interesting coincidence that this hole in the floor should happen to be immediately over the hole in the wall which caused this small fire in the first story. In almost any other part of the floor it would have been harmless.

On the platform near the west end was a bin filled with pine kindling wood piled against the south wall. A light surface fire ran over this pile, but was extinguished before doing serious damage, though some concrete was spalled from the ceiling. The thing of interest in connection with this little blaze is that it was evidently started by heated air coming through a 1 in. hole in the wall which was probably used during construction and had never been plugged.

***Second Story.***—The stable occupied the northern third of this story and was separated from the balance by an unpierced terra-cotta partition. No fire entered the stable.

The remainder of the floor area was congested with crates and racks filled with mattresses, bedding, house furnishing fabrics, and furniture. A surface fire ran over part of this material, but was extinguished before damaging the concrete construction except to spall the ceiling in places.

One pathway by which the fire entered this story was described under the heading "First Story", but it may also have entered by passing the fire doors protecting the doorway near the elevator. These doors did not fit the wall at some parts by $\frac{1}{2}$ in., and as the wall was only 8 in. thick, it is quite possible the highly heated air in the burning frame workshop was forced through these cracks and ignited nearby inflammable material.

***Third Story.***—The worst destruction occurred in this story, and its extent can be appreciated by a study of *Figs. 4 to 9.* The positions from which the photographs were taken are indicated on the plan of the story—*Fig. 2.* On this plan the columns, girders, and beams are lettered and numbered for convenient reference.

The western half of this story was devoted to general storage and to the manufacture of window screens. There was an oil and varnish storeroom in the north-west corner, as indicated on *Fig. 2.* It was surrounded by a 4 in. terra-cotta partition, with openings as shown, protected by fire doors. The small opening at the end was really a window protected by a metal-covered fire door with sliding panel for convenience in passing wooden material through to a small cutting-off saw located in the oil room. Workmen declare that both doors were closed, so how the fire gained entrance to the room is unknown. All evidence was destroyed by collapse of the floor above.

According to best information obtainable there may have been six or eight barrels of inflammable liquids in this storeroom. Certainly there was enough to produce intense fire, for practically everything burnable was consumed in this half of the story. Melted copper wire and thin brass indicated a temperature of 1,600° to 2,000° Fahr. Higher temperature may have obtained, but no evidence of fused cast iron or steel could be found, although numerous pieces of those metals were about.

The effect of this heat upon the concrete was most disastrous, but there is no evidence of fused concrete as occurred in the Edison fire.

Column 4 is badly shattered and failed by diagonal shear, producing an apparent settlement of about 3 in. *See Fig. 4.*

The pilaster column supporting the south end of beam No. 2 is considerably shattered, also the north-west corner column. *See Fig. 2.* Overhead beams, Nos. 3, 10, and 12, supporting the fourth story floor, have fallen, carrying with them the adjacent floor panels as indicated by the shaded area. Beam No. 11 is still in place but ruined. *Figs. Nos. 4 and 7* show the manner in which the floor panels broke away from the collapsed beams and remained hanging vertically to the adjoining beams by their reinforcement.

It should be noted that lack of overlap in the slab reinforcement, previously mentioned, has allowed the concrete to break between each sheet or unit width of reinforcement, so that they hang quite disconnectedly. Evidently there could have been little unity of action in these slabs. The design specified that these adjacent sheets of reinforcement should be wired together, but apparently this was not done.

It can also be seen that much of this reinforcement is lying extremely close to the under surface of the slabs, and did not have proper protection.

There was no fire in the fourth story immediately over this collapsed floor, and as failure did not occur until about 4.30 a.m., after the fire had been extinguished, the stock stored in the fourth story, consisting of gas stove crates, screen doors, and other combustible woodwork, which appears in *Figs. 4 and 5*, fell with the floors into the burned-out space and is not even scorched. There was no evidence of excessive load on these floors, and failure doubtless resulted from loss of structural strength, due to spalling of the concrete which exposed the reinforcement and permitted it to become overheated.

*Fig. 5* shows the conditions of girders A and B. They are both badly shattered and will probably have to be replaced. The hole at the middle of girder B, near the bottom, is where the lower reinforcing bars of beam No. 3 pulled out when it collapsed. The bent-up ribbed bar projected through the girder and is still seen in place. It will be noted that the bent-up bar, intended to resist the negative bending moments, was located on a line with the bottom of the floor slab, instead of being placed near the top surface, where it would have been much more effective, and where the design drawings indicated it should be. This same defect existed in all the collapsed beams.

*Fig. 6* is the south end of beam No. 3 where attached to the wall girder. The other ribbed bar can be seen where it was bent up into the top of the beam, also one of the stirrups attached to a lower bar.

On the eastern portion of this floor, beyond column No. 3, large quantities of wooden weather strips were stored in racks, also window sash, screen doors and similar material. At the extreme east end were some work benches and accessories.

There was evidently a hot surface fire in this area, but the burnable material was by no means consumed. It is recognized that such fuel as dry weather strips would burn vigorously on the surface, but when stacked in compact piles, as was the case here, the fire would be slow in penetrating them. A large proportion of this material was not burned and the fire did not last long enough to consume the work benches and other wooden material in this area. No fused metal could be found, and the temperature was probably not in excess of 1,500° to 1,700° Fahr.

*Figs. 7 and 8* are views looking in opposite directions over this eastern portion of the story and show the havoc produced on the concrete construction, also the amount of unburned material on the floor. The hanging floor panels in *Fig. 7* have been previously described, and belong to the disaster which occurred in the rear or western portion of the story.

Columns Nos. 3 and 4 are badly spalled and some reinforcement is exposed and buckled, but they do not appear to have sheared or to have settled. They can probably be repaired.

All the beams and girders shown in *Fig.* 7 and those in the foreground of *Fig.* 8 are badly spalled and shattered. Most of them show diagonal shear cracks near the ends, and ¼ to ½ in. cracks along the top next to the floor slabs. The fractures indicate that the beams and floor slabs were cast monolithic; it is therefore not quite clear why these cracks occurred unless due to unequal expansion of beams and floor slabs. Possibly the rapid expansion of the lightly loaded floor being resisted by the beams from deflecting downwards arched upwards and broke connection with the beams by overcoming the tensile strength of the concrete.

*Fig.* 9 shows details of these cracks in two of the beams. Considerable settlement has occurred in several of these members, and it is probable that they will have to be replaced or be substantially strengthened, as was done in repair of beams at the Edison plant.

Aside from numerous cracks, the floor slabs are not badly damaged. The cracks in the floor slabs throughout the building contributed generously to water damage. To what extent these cracks existed before the fire is not known, but from their appearance it is reasonably certain that a fair proportion of them have existed for some time. Such cracks are also found in the floors that were not subject to fire.

It is generally assumed that the fire entered this story through the doorway near the elevator, but there is conflicting testimony as to whether the fire doors were open or not. Certain it is that fire was burning on this floor within 10 to 15 minutes after the fire in the frame factory was discovered.

It is possible the fire may have been communicated by air heated to the point of combustion being forced past the loosely fitting fire doors even though closed. Whether this were the case or not is immaterial so far as fire in this story is concerned, for there was another abandoned steam pipe hole through the floor of the third story about 15 ft. east of the fire doors, and just over area where the fire was hottest in the second story. It is therefore quite certain that fire passed through this opening and it may reasonably have been the only channel by which it entered the third story.

***Fourth Story.***—The rear portion of this floor which fell into the third story was stocked with gas stoves in crates, and the balance with furniture and house furnishings. The story was divided by a thin pine board partition on a line with column No. 3. A flash fire ran over the stock in the south-east portion within the area bounded by beam No. 5 and girders C, D, and E.

There was a heavy stock of furniture on the north side, but it was only scorched and the pine board partition proved an effectual barrier to the west.

The fire was brisk in the corner east of the elevator shaft and burned considerable furniture there. *Fig. 10* shows this corner and the damage to the wall girder, pilaster column, beam No. 6 and the floor panel. All of these were badly spalled and the terra-cotta elevator partition collapsed near the top. In the south-east corner of the story there is a ½ in. vertical crack between corner column and the adjoining wall panel.

There are numerous large cracks in various parts of the floor in the eastern portion, due probably to the heat expansion described in remarks upon the "Third Story". The rising of the floor in place indicated arching.

The stairway partition fell from shock of the falling floors, and the surface flooring over beams 1 and 2 is much broken. Column No. 4 and the girders and beams resting on it are seriously cracked, due to settlement consequent upon failure of the column beneath in the third story.

The fire probably entered either through a 1 in. hole in the wall panel near the elevator or around the brick wall built to cut off a window which had existed above the roof of the adjoining frame factory. This brick wall had settled away from the main wall about ¼ in., and the glass in the window on the outside had fused and fallen from the sash.

***Fifth Story.***—There was a row of small private storage rooms with corrugated metal partitions and doors along the north wall. These as well as the whole floor area were filled with household goods.

No fire occurred in this story and structural damage is limited to some bad cracks in column No. 4 and the attached beams and girders due to settlement. Also wall girder F in the south-east corner has kicked out about ¾ in., and there are serious cracks in the girder and the adjacent floor panels.

***Sixth Story.***—Used for storage of household furnishings. No fire in this story.

Structural damage limited to settlement of column No. 4, producing large cracks at the top. There are also some prominent cracks in wall girder F in the south-east corner.

***Seventh Story.***—The story was fairly well filled with furniture stock in crates and racks; there were also some thin wooden partitions, and a carpet cleaning machine. A surface fire spread over the portion of the floor area east of column No. 4, but a wooden partition across the building near this column held the fire from extending to the western end. Only a small part of the combustible material was consumed. Even paper and excelsior wrappings on furniture stored on the central portion of the floor were unburned. Nevertheless, there was a flash fire in other portions and a number of the overhead roof beams were spalled sufficiently to expose the bottom reinforcing bars for several feet, but no very serious damage was done. Column No. 4 is cracked near the top, and the intersecting girders and beams are cracked away from the column. There was no fire around this column and the damage resulted from settlement due to failure of the column under it in the third story. (*See Fig. 11.*)

How the fire entered this story is unknown.

***Roof.***—The western end of the roof was enclosed by an 8 ft. parapet 7 in. thick. About 20 ft. of the extreme west end was roofed over with corrugated metal and a partition of the same construction extended across the building north and south connecting with the roof structure, which covered the elevator shaft and provided an elevator landing on the roof. The roof surface had a composition tar or asphalt roof covering.

The enclosed room gives evidence of a hot fire of considerable duration. Everything combustible is consumed, including the roof covering. There were some work tables here and a few rugs hung up to dry after cleaning, but it is claimed there was little other combustible material. Numerous 5 gal. tin cans are lying about, but both the owner of the building and employees declare they were empty.

As this fire was quite inaccessible, it appears to have been allowed to burn itself out, and while everything burnable was consumed, there is no evidence of high heat.

The east parapet wall had no pilasters to stiffen it, and the expansion due to heat threw it outwards, making a crack at each corner $1\frac{1}{2}$ in. wide at the top and extending downward to the roof. One of these cracks can be seen in *Fig. 1.* No reinforcement could be seen in these corners.

***South Exterior Wall :*** This wall was subjected to the full force of the fire from the burning woodworking factory and it is severely punished, as can be seen by inspection of *Fig. 1.* Large areas of the wall surface covered by the wooden building, as well as the two stories immediately above the roof, are badly spalled. Frequently these spots from which the concrete scaled are several square feet in area and 2 to 3 in. deep. The reinforcement was probably placed near the inner face of the wall as but little of it is exposed. The wall opposite the fourth and fifth stories appears to be somewhat wavy, as if it had buckled, and there are several prominent cracks. Whether any of these existed before the fire is unknown.

The softening and collapse of all four-wired glass windows above the roof at the east end proves the intense heat thrown against this part of the building.

***West Exterior Wall :*** This wall is buckled outwards between the third and fourth story windows an inch or more, and appears to be somewhat wavy in the stories above. There are numerous prominent cracks, one of which zigzags completely across the building. See *Fig. 1.* This injury seems to have resulted from the movement of the interior cross girders due to the settlement of the line of column No. 4 above the failure in the third story.

The bottom of the parapet wall is thrust outwards an inch half-way across the building. The north-west corner of the parapet is shattered and parts have fallen.

All the windows were broken out by firemen except a few in the row of small windows near the south-west corner, where the glass was softened by heat and dropped from the sash. See *Fig. 1.* These windows lighted the stairway shaft. The fire entered the shaft through these windows, but as there was nothing to burn, no harm ensued except to make the stairway untenable at these points. The firemen report that they entered the stairway at the fourth floor and fought the fire from it on the floors above. They reached the fourth story by ladder.

***North Exterior Wall :*** Numerous cracks, some 6 to 10 ft. long, appear on the western portion of this wall opposite the third and fourth stories. These were doubtless connected with the interior failures. Other cracks were found, but they appear to be old expansion cracks.

***East Exterior Wall :*** Numerous diagonal cracks are apparent on the face of this wall, but to what extent they existed before the fire was not learned.

## GENERAL DISCUSSION AND CONCLUSIONS.

1. The one fact which stands out above all others in connection with this fire is that a suitable sprinkler system would have saved the concrete building with its contents and probably have controlled the fire in the frame building. It is one more demonstration of the folly of depending upon fire-resistive construction alone to protect inflammable contents of a building from fire. The owners had evidently made sincere effort to have a very safe structure. It was in general well built; wired glass windows were provided on all sides; the protection of vertical openings were standard; double approved fire doors were provided on communicating doorways; sets of fire pails properly filled were scattered about each floor, but were useless because of the smoke which entered the building preceding the fire. With all these precautions the building is to-day badly wrecked; a large proportion of the contents are ruined either by fire or water, and a total property loss of $125,000 (£25,000) or more has been sustained. Only a portion of this is covered by insurance and the business of the owners will be more or less paralyzed for many months. All this could have been saved by a comparatively small investment in sprinkler protection.

2. Although the area was not excessive, nevertheless it is quite apparent that had the floor space been divided by partition of even moderate fire-resistive capacity the fire would have been localized and a large proportion of the damage prevented. In two stories—the fourth and seventh—plain pine board partitions held the fire from spreading until firemen were able to extinguish it.

3. The folly of erecting a high grade fire-resistive building in all essential structural features and then allowing its efficiency to be ruined by permitting unprotected openings, even of small size, in walls and floors was strongly emphasized. The fact that fire was distributed from story to story by 3 and 4 in. pipe holes and that in at least one instance it was transmitted through a 1 in. hole in a fire wall indicates the extreme care and ferret-like inquisitiveness which insurance inspectors must exercise if they furnish their companies with complete and reliable estimates of the fire hazards which exist in a building. Any type of well-constructed fire-resistive building, with all the ordinary wall and floor openings properly protected, may be a dangerous fire risk if even small holes or cracks are allowed to exist in exposed walls, or in floors or partitions. Air and gases of combustion in a burning room are under more or less pressure due to the rapid expansion caused by heat. Under such conditions they will be forced through very small openings, and if their temperature is 1000° Fahr. or over, which quickly obtains in a fire of any size, they will ignite almost every inflammable object they touch. This fact is extremely important, but unfortunately often overlooked.

4. So far as the reinforced concrete building itself is concerned, the most impressive feature of its appearance is the extent of the damage done, which seems to be quite disproportionate to the severity of the fire. With the exception of the exterior south wall, exposed to the adjoining burning building, and a portion of the third story, where a few barrels of oil and other inflammable liquids were burned,

there were no indications of very hot or long continued fire. In the areas covered by the two exceptions all combustible material was consumed, and there is evidence of fairly high temperature, probably 2000° Fahr. In all other places where fires occurred, it is plainly to be seen that they were flash surface fires of short duration. They consumed only a small portion of the very combustible material on which they fed, and were in all cases extinguished before attacking surrounding inflammable material, and yet the damage to the concrete construction was severe.

It is this aspect of the fire which gravely concerns the underwriters, for if similar impairment is always liable to be found when a concrete building burns out, that probability must be taken into account when assuming the risk. The subject is of equal importance to owners. A logical explanation of the phenomena is therefore necessary for future guidance.

The damage described is much worse than we would expect, having in mind the effects produced by many four-hour fire tests which we have conducted upon reinforced concrete floor construction. In proportion to the fire the damage to floor construction is worse than in the Edison plant.

5. The Edison plant fire * and fires elsewhere in reinforced concrete structures, have taught us that the rapid surface expansion of concrete when subjected to a quick fire, is destructive to structural members with sharp corners. Square columns and beams should, therefore, be avoided. This subject was discussed at length in our report on the Edison fire, and round columns are recommended in the National Board of Fire Underwriters' Building Code, U.S.A.

The 1916 Report of the Joint Committee on Concrete and Reinforced Concrete, U.S.A., which is a recognized authority in this country, says :

" The corners of columns, girders and beams should be bevelled or rounded, as a sharp corner is more seriously affected by fire than a round one ; experience shows that round columns are more fire-resistive than square."

Recent " Recommended Specifications for Reinforced Concrete Design ", issued by the Portland Cement Association, U.S.A., specifies that " All interior columns shall be round ".

Inspection of the photographs will show that the columns and girders in this building were bevelled, but it was not enough to be of real service. This is another important lesson emphasized by this fire. Only round columns, or those closely approaching that shape, should be used on the interior of a building.

6. The safety of beams is scarcely less vital than columns, but it is difficult to round them sufficiently to avoid spalling, and at the same time properly protect the reinforcing bars. This difficulty can be overcome by using some form of mesh reinforcement surrounding the main reinforcement bars on the bottom and supported by them, similar to the methods employed to hold concrete fireproofing on steel I beams. The added cost would be slight and the increased security when attacked by fire would be very material.

These faults in the structural shapes cannot be charged to defective design, for the " state of the art " at the time this building

* *See B.F.P.C. " Red Books " Nos.* 204 *and* 207.

was erected had not sufficiently advanced to recognize them as weaknesses.

Perhaps the best solution of the problem may be found in the elimination of beams entirely and using flat slab construction. Unfortunately this form of construction is comparatively new, and we have not as yet secured sufficient testimony regarding its behaviour, when attacked by fire to judge its merits as a fire-resistant as compared with the older forms of construction.

7. A certain amount of the damage which ensued in this building can justly be credited to improper shape of structural members, and doubtless some of it may be explained by the fact that water was thrown upon the concrete while hot. The deficient concrete protection to the reinforcement probably also contributed to the failure; however, considering the freedom with which the concrete spalled from the reinforcement bars, it is questionable whether a thicker protection of this concrete would have rendered more efficient service. This excessive spalling seems inconsistent with what past performance has taught us to expect, especially when we consider the moderate fire which produced it, and we are extremely loath to believe that all concrete would exhibit the same weakness under like conditions.

The concrete itself appears to be good. Where not disintegrated by heat it is clean and dense. What then was the trouble? In the writer's opinion it was the use of quartz gravel for the coarse aggregate.

During the years 1905, 1906, and 1907 the writer conducted an "Investigation of the Thermal Conductivity of Concrete Mixtures, and the Effect of Heat upon their Strength and Elastic Properties". This work was done for the American Society for Testing Materials, and the final report was published in the Proceedings of the Society for 1907. In this he said:—

"Although the thermal-conductivity of the gravel concrete was fully as low as that of the trap,* it must nevertheless be condemned as a first-class fire-resisting mixture. All the specimens of gravel concrete tested were badly disintegrated by the heat. The gravel specimens would crack and crumble in pieces when the trap and cinder specimens under similar treatment would remain firm and compact. These results are in complete confirmation of those reported last year which were received by some of the membership with considerable scepticism. The writer is convinced that concrete made from this particular gravel is not reliable as a fire-resisting material. Whether other grades of gravel would give equally unsatisfactory results is a matter for investigation.

"The cause for this failure of the quartz mixture is not easy to locate. The most plausible reason seems to be the relatively large co-efficient of expansion of the quartz. It is about twice that of feldspar, which is one of the predominant minerals in trap rock. Clark's 'Constants of Nature', published by the Smithsonian Institute, gives the cubical co-efficient of expansion for these minerals as follows:—

| | |
|---|---|
| Quartz . . . . . | ·000036 |
| Feldspar . . . . . | ·000017 |

"According to the same authority, quartz has another peculiarity of expansion, viz., that the expansion in the direction of the major axis is only half that in the direction of the axis perpendicular to the major axis. This

* *See* Memorandum as to "trap" on page 21.

unequal expansion may further contribute to its tendency to disintegrate the concrete under action of heat.

"Since the distribution of gravel is much more general than trap, the subject is of much importance, and tests should be made to determine if other gravels are equally defective."

Also one of the conclusions in the "Summary" of that report was "That the gravel concrete was not a reliable or safe fire-resisting aggregate".

That restriction applied only to pure quartz gravel such as is found in the vicinity of New York City, and similar to that used in the concrete for this building. It might be added that subsequent investigations by the British Fire Prevention Committee of England upon a quartz gravel there confirmed our findings.

The behaviour of the concrete in this fire appears to confirm the criticism above mentioned. Whether the oversize gravel exaggerated the effect is not known.

If this explanation is correct, as evidence thus far produced seems to sanction, all concrete specifications should contain a definite warning against the use of quartz gravel in concrete liable to be exposed to high heat. Where it is so used, underwriters should take that fact into account when assuming the risk.

**8.** In so far as the construction of this building did not follow the design, it is an example of the objectionable practice of divided responsibility which has frequently been criticized in the technical press.

**9.** Whether a steel frame building properly fireproofed would have rendered better service in this fire is, of course, problematical, but it is doubtful if it would have been less satisfactory. That question, however, has no direct relation to the purpose of this report.

**10.** The water damage due to leakage in stories not attacked by fire was considerable. The construction of reliable waterproof floors in fire-resistive buildings of all types is a subject which has not received the attention it deserves by underwriters. Not infrequently the water damage in such buildings is far in excess of the fire damage. This is illogical and unnecessary. Inspectors should give specific attention to this feature in fire-resistive buildings.

**11.** The storage of inflammable liquids in quantity inside this building—particularly in an upper story—is simply another violation of a well-known regulation for safe storage of such materials. It should never be permitted.

## *NOTE TO CONCLUSIONS.*

It should be stated that the weakness of quartz gravel concrete, as discussed in paragraph 7, is due to a general disintegration of the mass and not as might be supposed to fracture of the pebbles themselves. Very few broken pebbles are found in such ruptured concrete. Quartz pebbles are usually made up of a mass of interlocking crystals, and although the unequal expansion of these crystals along their axes is microscopical in character, it can easily be conceived that each pebble when highly heated would be subject to numerous unbalanced internal expansion stresses tending to produce an agitation of the surface of the pebble which would contribute to breaking the bond between the pebble and the mortar in which it was embedded. Some evidence produced seems to indicate this, but the extent of such action is of course purely speculative. It may be found that the smooth surface of the gravel is the principal cause of weakness, though some tests upon concrete made of gravel other than quartz would not imply this.

To what extent the quality of the cement used might by chance have contributed to the results observed is quite unknown, but as before stated, simple inspection of the concrete did not indicate inferior material. In the investigation quoted, cement from the same bag was used in making the specimens, and samples of each gave satisfactory strength tests.

Whatever the deteriorating cause or causes may be, it is quite certain that evidence thus far at hand is prejudicial to quartz gravel concrete liable to be subject to fire. The matter is one of great importance to the concrete industry, and a complete investigation of the problems involved should be made by some qualified scientific authority.

# MEMORANDUM.

*The term "trap" is frequently used in reports of American buildings as descriptive of a local concrete aggregate, and having regard to the many inquiries received to define this class of aggregate, the following memorandum kindly prepared by Mr. Arthur Holmes, D.Sc., is presented by the British Fire Prevention Committee for the use of its members and subscribers:—*

The term *Trap* dates to the time when there were no means of recognizing small distinctions among rocks, and when the origin of many was incompletely understood. It was eventually determined that the rocks to which the term was applied were igneous in origin, and often of considerable age, and they were broadly distinguished from the coarse, acid, granitic rocks on the one hand, and from the cellular, loose-textured, recent, and obviously volcanic rocks on the other. The rocks were very widely distributed and included those which, in modern phraseology, would be called dolerite, basalt, porphyrite, andesite, phonolite, porphyry, and pitchstone, together with altered varieties of some of these, known as epidiorite, diabase,* and melaphyre. When now used, the term *trap* is generally confined to the first four types, which are sometimes grouped together as *whinstone*, and the last three, which are often referred to, and shown on maps, as *greenstone*. Both types of rocks are somewhat basic in composition, and their specific gravity ranges from 2·7 to 3·1. The whinstones range in colour from dark grey to nearly black, through various tints of blue, purple, or brown; whereas the greenstones, as the name implies, more often exhibit greenish tints. When the rocks are jointed, the fracture surfaces are often coated with a deposit of rust due to weathering.

The *whinstone* group consists of comparatively unaltered igneous rocks, intrusive or interbedded, having a crystalline texture not usually coarse, and made up chiefly of the minerals felspar, augite, and iron ores, with or without hornblende, hypersthene, or olivine. The *greenstone* group represents different stages in the alteration of rocks of the whinstone group. One or more of the original minerals is decomposed or altered, and in some cases amygdaloids have been formed by the deposit of secondary minerals in cavities. The alteration products and secondary minerals include kaolin, mica, epidote, hornblende, chlorite, serpentine, limonite, chalcedony, calcite, and zeolites.

For the manufacture of concrete the whinstone group is likely to be more successful than the greenstone group, as the decomposition of the minerals in the latter may result in an unsatisfactory loosening of texture. Dolerite, which is a typical whinstone, expands by only 2–3 per cent of its volume on being heated to 1200° F., the corresponding figure for granite being over 6 per cent. At higher temperatures the contrast is still more striking, indicating the marked superiority of dolerite and allied rocks from the point of view of fire-resistance.

ARTHUR HOLMES.

*18th January*, 1918.

* The term diabase is sometimes used, and especially by American authorities, in the same sense as dolerite is used above.

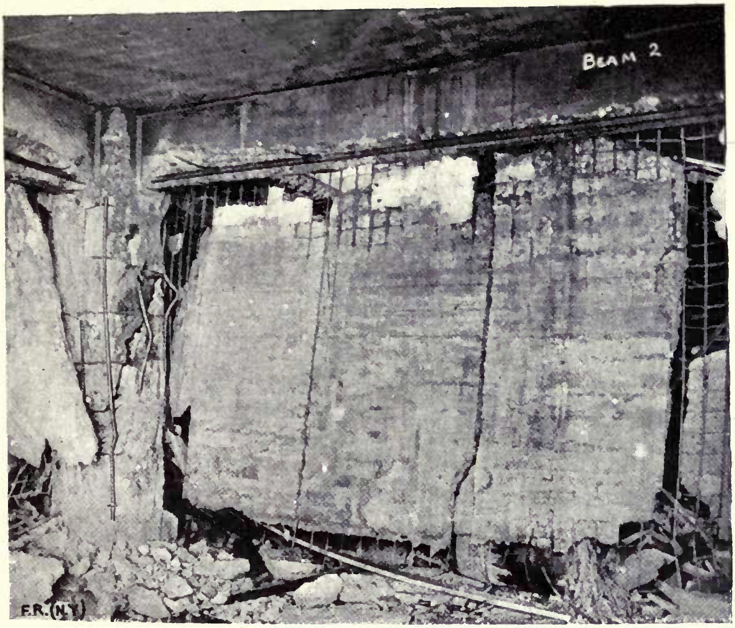
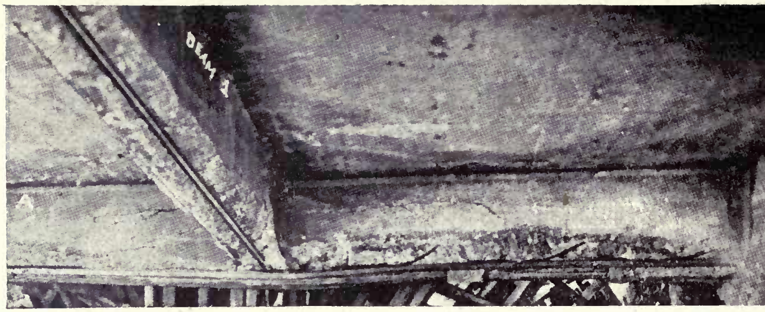



*Fig.* 4.—View of column No. 4, girder A, and beam No. 2 in third story. Also portions of collapsed fourth floor hanging to beam in disconnected portions. Note exposed reinforcement in all members.


*Fig.* 10.—Effect of fire corner next to elevator in fourth story. Terra-cotta elevator partition has partially collapsed. Note spalled pilaster column and wall girders, also exposed reinforcement in floor slab.




Girder A in third story. Note separation from floors, and diagonal cracks in girder.


Girder B in third story. The ribbed bar on the right belonged to fallen beam No. 3. The hole in bottom of girder is where the trussed bar pulled out.

Connection of fallen beam No. 3 with wall girder in third story.
(*Figs.* 5 *and* 6.)


*Fig.* 7.—Looking westward in third story showing column No. 3 with connecting beams and girders, also hanging floor slabs broken away from fallen beams Nos. 3 and 12. Note disconnected slab units, spalled concrete, and exposed reinforcement.

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*Fig.* 8.—Looking eastward in third story, showing character of injury to concrete. Note unburned material on floor, also in Fig. 7.


*Fig.* 9.—Details of fractures in beams Nos. 4, 5, and 6 in third story. Note separation of beams from floor slab.

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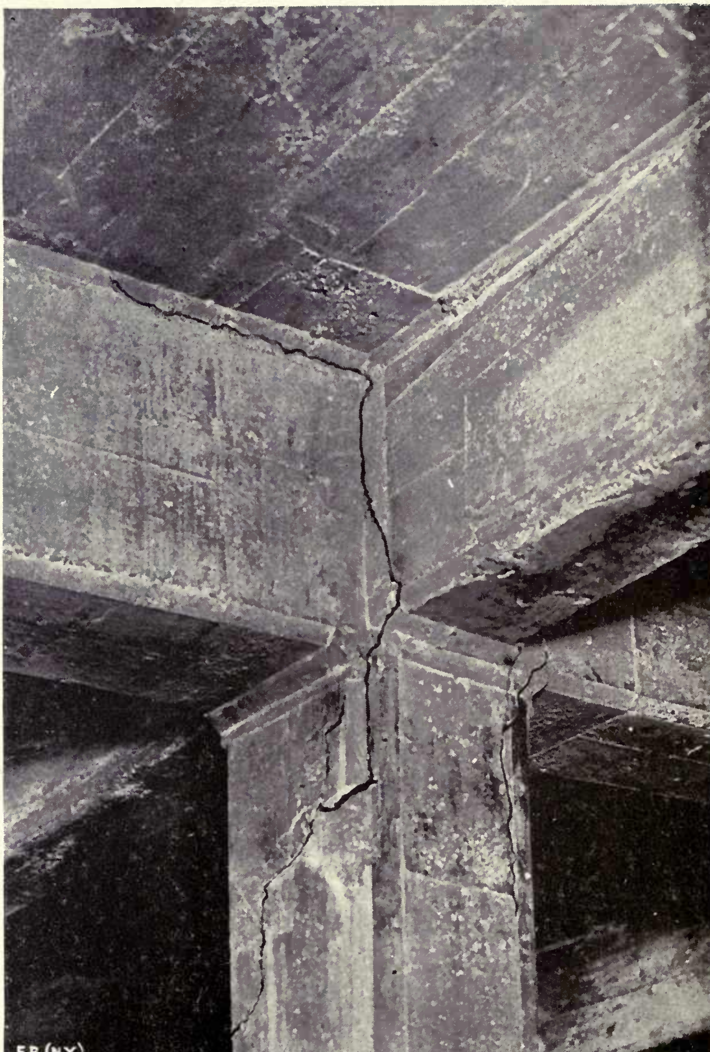


*Fig.* 11.—Top of column No. 4 with connecting beams and girders in seventh story. Note cracks due to settlement of column.