

[Document Type] Specification

[Title of the Invention] METHOD OF DESIGNING FIRE RESISTANT
STRUCTURE, METHOD OF CONSTRUCTING FIRE RESISTANT STRUCTURE,
AND FIRE RESISTANT STRUCTURE

[Technical Field of the Invention]

[0001]

The present invention relates to a method of designing a fire resistant structure,
a method of constructing a fire resistant structure, and a fire resistant structure.

Priority is claimed on Japanese Patent Application No. 2018-221045, filed
November 27, 2018, the content of which is incorporated herein by reference.

[Related Art]

[0002]

In the related art, steel framed structures are known (see, for example, Non-
Patent Document 1). Steel framed structures are configured by connecting columns
and beams to each other and supporting a floor (slab) on the beams. The floor is
formed in a rectangular shape having a plurality of corner portions in a plan view. The
columns support each of the plurality of corner portions of the floor from below.

In structures, there may be cases where columns and beams of a steel framed
structure are subjected to a fireproof coating in order to improve fire resistant
performance such as suppressing the deflection of a floor if there is a fire. A column
subjected to a fireproof coating becomes a protected column with fireproof coating. A
beam subjected to a fireproof coating becomes a protected beam with fireproof coating.

[0003]

When a fire occurs in a structure, the temperature of columns and beams rises.
However, protected columns with fireproof coating and protected beams with fireproof

coating maintain a certain degree of stiffness and strength even when their respective temperatures rise. Therefore, the protected columns with fireproof coating and the protected beams with fireproof coating can support a floor even if there is a fire. On the other hand, columns and beams that are not subjected to a fireproof coating and columns and beams with a reduced fireproof coating compared to the protected columns with fireproof coating and the protected beams with fireproof coating lose stiffness and strength (cannot maintain stiffness and strength) if there is a fire. If there is a fire, there may be cases where such stiffness and strength are considered to be reduced. Fire resistant performance is reduced in structures with columns, beams, and the like that are not subjected to a fireproof coating.

Since it takes a lot of effort to subject the columns and beams to the fireproof coating, it is desired to omit the fireproof coating.

[0004]

In general, a structure is composed of columns, beams, slab, and the like. The slab includes a tensile force transmitting member. For example, the tensile force transmitting member is a reinforcing bar. The structure becomes a fire resistant structure by subjecting the column to a fireproof coating to obtain a protected column with fireproof coating or by subjecting the beam to a fireproof coating to obtain a protected beam with fireproof coating. The slab is partitioned by columns and beams into a rectangular floor portion having a plurality of corner portions in a plan view.

[0005]

As illustrated in FIG. 30, in a method of designing a fire resistant structure for designing a fire resistant structure 300 disclosed in Patent Document 1, a beam member 303 is set to be connected between a protected column member with fireproof coating 301 and a protected column member with reduced fireproof coating 302. In FIG. 30

and below, columns and beams subjected to a fireproof coating without reducing the fireproof coating are hatched.

The protected column member with fireproof coating 301 is a column member subjected to a fireproof coating. The protected column member with reduced fireproof coating 302 is a column member having a reduced fireproof coating compared to the protected column member with fireproof coating 301.

In a plan view of the fire resistant structure 300, a plurality of protected column members with fireproof coating 301 and a plurality of protected column members with reduced fireproof coating 302 are disposed side by side at intervals in each of a width direction E1 and a depth direction E2. The plurality of protected column members with fireproof coating 301 and the plurality of protected column members with reduced fireproof coating 302 are disposed in a grid pattern as a whole. At this time, the column members adjacent to the protected column members with reduced fireproof coating 302 in the width direction E1 and the depth direction E2 are disposed so as to be the protected column members with fireproof coating 301. The beam members 303 connect the plurality of protected column members with fireproof coating 301 and the plurality of protected column members with reduced fireproof coating 302 disposed in a grid pattern.

[0006]

A composite slab 304 is placed on a plurality of the beam members 303. Although not illustrated, the composite slab 304 has a concrete, a deck plate, and a reinforcing bar (tensile force transmitting member). The deck plate is fixed to the upper surface of the beam member 303 by driving tack joints, bolt joints, or the like.

In the fire resistant structure 300 configured as described above, the protected column member with fireproof coating 301 can maintain stiffness and strength not only

when the outside air temperature is a normal temperature but also if there is a fire. On the other hand, the protected column member with reduced fireproof coating 302 can maintain stiffness and strength in normal times, but cannot maintain stiffness and strength if there is a fire. If there is a fire, the stiffness and strength of the protected column member with reduced fireproof coating 302 are considered to be lost.

[0007]

The fire resistant structure 300 if there is a fire is deformed as illustrated in FIGS. 31 and 32. In FIG. 31, the composite slab 304 is not illustrated. In FIG. 32, the protected column member with reduced fireproof coating 302 and the composite slab 304 after the deformation are shown by two-dot chain lines.

In FIG. 31, the composite slab 304 disposed on a centerline M1 connecting the adjacent protected column members with fireproof coating 301 is hereinafter referred to as a slab 304a on the line. The protected column members with fireproof coating 301, the protected column members with reduced fireproof coating 302, the beam members 303, and the composite slabs 304 are affected by gravity not only in normal times but also if there is a fire.

[0008]

Since the stiffness and strength of the protected column members with fireproof coating 301 can be maintained if there is a fire, as illustrated in FIGS. 31 and 32, the position of the slab 304a on the line in an up-down direction E3 is maintained even if there is a fire. Contrary to this, since the protected column member with reduced fireproof coating 302 loses its stiffness and strength if there is a fire, the protected column member with reduced fireproof coating 302 moves downward (bends) as shown by two-dot chain lines in FIG. 32.

Since the positions of portions other than the slab 304a on the line in the up-

down direction E3 are not held, each portion of the composite slab 304 moves downward by gravity acting on the composite slab 304 in a direction away from the slab 304a on the line. Therefore, if there is a fire, the composite slab 304 is curved so as to be convex upward with the slab 304a on the line as the center.

In the curved composite slab 304, the concrete receives a compressive force and the reinforcing bar receives tensile force, so that the composite slab 304 withstands a bending moment B1. The composite slab 304 resists the gravity acting on the composite slab 304 by the bending moment B1.

[0009]

As described above, in the fire resistant structure 300, the fireproof coating of the protected column member with reduced fireproof coating 302 is reduced compared to that of the protected column member with fireproof coating 301. However, in the fire resistant structure 300, robustness (redundancy, margin) of the framework of the fire resistant structure 300 occurs. Due to this robustness, the composite slab 304 is supported by the protected column members with fireproof coating 301 if there is a fire, even if the fireproof coating of the protected column member with reduced fireproof coating 302 is reduced.

[0010]

In a method of calculating an explosion-proof and fireproof film thickness disclosed in Patent Document 2, a specimen including a concrete structure and an explosion-proof and fireproof coating layer provided on the surface of the concrete structure is produced. Then, the specimen is heated, the change in temperature with time is measured, and the relationship between the depth and the temperature of the specimen is derived. Based on this relationship, it is determined whether or not the temperature of the concrete structure is equal to or lower than a heat resistance

allowable temperature. Furthermore, the thickness of the explosion-proof and fireproof coating layer is calculated based on the result.

[0011]

As illustrated in FIG. 33, a slab structure 311 disclosed in Patent Document 3 is used for a building 310. The slab structure 311 includes primary beams 312, secondary steel beams 313, and a slab 314. The primary beams 312 have fire resistant performance and are laid between columns 315. The entirety or a portion of the secondary steel beam 313 is not subjected to a fireproof coating treatment. The secondary steel beams 313 are connected to the primary beams 312. The slab 314 is made of reinforced concrete. The slab 314 is supported by the primary beams 312 and the secondary steel beams 313.

[0012]

Here, among a plurality of the columns 315, the columns 315 located in the periphery the slab 314 are defined as outer columns 315A. The columns 315 other than the outer column 315A among the plurality of columns 315 are defined as inner columns 315B. In a plan view, a first reference line C1 that passes through the center (for example, the center of gravity) of the inner column 315B and the center of the outer column 315A and reaches the periphery of the slab 314 is defined. A second reference line C2 passing through the centers of the inner columns 315B is defined.

Here, in a plan view, the slab 314 is partitioned into floor portions 314A, 314B, and the like by at least one of the first reference line C1 and the second reference line C2. The floor portions 314A, 314B, and the like have a rectangular shape in a plan view. The floor portions 314A, 314B, and the like are partitions on the design (design partitions) in which the corner portions are not chipped by the columns 315.

In a plan view, all the corner portions of the floor portions 314A, 314B, and the

like are disposed so as to overlap the plurality of columns 315.

[0013]

Hereinafter, in the present specification, the shape of the floor portion partitioned from the slab in a plan view means the shape of the floor portion partitioned from the slab by the line passing through the center of the column and the periphery of the slab.

[0014]

A fire resistant structure disclosed in Patent Document 4 includes a plurality of column members, a plurality of primary beams, a secondary beam, and a floor slab.

Each primary beam is placed on the column members. The plurality of primary beams have a pair of orthogonal primary beams provided substantially orthogonal to the secondary beam and a pair of parallel primary beams provided substantially parallel to the secondary beam. One (hereinafter, referred to as a first primary beam) of the orthogonal primary beams and the parallel primary beams are subjected to a fireproof coating. The fireproof coatings of the primary beams which are the other of the orthogonal primary beams and the parallel primary beams and the secondary beam are reduced compared to the fireproof coating to which the first primary beam is subjected. The secondary beam is provided inside surrounded by the plurality of primary beams. The floor slab is provided above the primary beams and the secondary beam.

[Prior Art Document]

[Patent Document]

[0015]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2017-031592

[Patent Document 2] Japanese Unexamined Patent Application, First
Publication No. 2008-303646

[Patent Document 3] Japanese Unexamined Patent Application, First
Publication No. 2017-190586

[Patent Document 4] Japanese Unexamined Patent Application, First
Publication No. 2018-003556

[Non-Patent Document]

[0016]

[Non-Patent Document 1] Olivier Vassart, Bin Zhao “MEMBRANE
ACTION OF COMPOSITE STRUCTURES IN CASE OF FIRE”, 2013 No.132, ECCS,
Technical Committee 3 Fire Safety.

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0017]

In the methods of designing a fire resistant structure disclosed in Patent
Documents 1 and 2, the shape of the floor portion partitioned from the slab is not
specified. In the methods of designing a fire resistant structure disclosed in Non-
Patent Document 1 and Patent Documents 3 and 4, the shape of the floor portion in a
plan view is rectangular.

With the diversification of the configurations of fire resistant structures, it is
desired that the floor portion can maintain a certain fire resistant performance even if
the shape of the floor portion is a polygonal shape different from a rectangular shape.
The fire resistant performance of the floor portion mentioned here means suppressing
the deflection of the floor portion if there is a fire or suppressing an increase in external
forces compared to the bending strength of the floor portion.

[0018]

The present invention has been made in view of such problems, and an object thereof is to provide a method of designing a fire resistant structure, a method of constructing a fire resistant structure, and a fire resistant structure capable of maintaining a certain fire resistant performance while allowing the shape of a floor portion to be a polygonal shape different from a rectangular shape.

[Means for Solving the Problem]

[0019]

In order to solve the above problems, the present invention proposes the following means.

(1) According to a first aspect of the present invention, there is provided a method of designing a fire resistant structure, in which the fire resistant structure includes a plurality of protected columns with fireproof coating subjected to a fireproof coating, a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other, and a floor portion partitioned from a slab including a tensile force transmitting member, in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner columns with fireproof coating, in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and

a second centerline which passes through the centers of the protected inner columns with fireproof coating, in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape, in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating, the plurality of protected beams with fireproof coating are formed in a ring shape as a whole, the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction, the method including: a structure determination step of determining a disposition of the slab, a plurality of beams supporting the slab from below, and columns supporting the plurality of beams by performing a structural calculation; and a fire resistant specification determination step of performing setting so that the periphery of the floor portion partitioned from the slab is supported from below by the protected beam with fireproof coating obtained by subjecting the beam to the fireproof coating.

[0020]

(2) In the method of designing a fire resistant structure according to (1), in the fire resistant specification determination step, a first floor piece partitioned into a predetermined shape in the plan view is used as the floor portion, a determination step of determining whether or not a principal stress of compression of the floor portion exceeds a predetermined stress threshold is performed, and when it is determined in the determination step that the maximum value of the principal stress of the compression

occurs in a peripheral portion that is a portion of the periphery of the floor portion and the maximum value of the principal stress of the compression exceeds the predetermined stress threshold, at least the fire resistant specification determination step is performed assuming that the floor portion is partitioned into a shape including the first floor piece and a second floor piece connected to the peripheral portion of the first floor piece and the floor portion has a polygonal shape different from a rectangular shape in the plan view, and the determination step is further performed.

(3) In the method of designing a fire resistant structure according to (1), in the fire resistant specification determination step, it is assumed that the floor portion has a polygonal shape different from a rectangular shape in the plan view, and a determination step of determining whether or not a principal stress of compression of the floor portion exceeds a predetermined stress threshold is performed.

[0021]

(4) According to a second aspect of the present invention, there is provided a method of designing a fire resistant structure, in which the fire resistant structure includes a plurality of protected columns with fireproof coating subjected to a fireproof coating, a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other, and a floor portion partitioned from a slab including a tensile force transmitting member, in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner columns with fireproof coating, in the plan view, the floor

portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating, in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape, in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating, the plurality of protected beams with fireproof coating and a portion of the plurality of protected columns with fireproof coating are formed in a ring shape as a whole, the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction, the method including: a structure determination step of determining a disposition of the slab, a plurality of beams supporting the slab from below, and a plurality of columns supporting the plurality of beams by performing a structural calculation; and a fire resistant specification determination step of performing setting so that the periphery of the floor portion partitioned from the slab is supported from below by the protected beam with fireproof coating obtained by subjecting the beam to the fireproof coating and a portion of the plurality of protected columns with fireproof coating obtained by subjecting the plurality of columns to the fireproof coating and the plurality of protected beams with fireproof coating are formed in a ring shape as a whole.

[0022]

(5) According to a third aspect of the present invention, there is provided a fire resistant structure designed by the method of designing a fire resistant structure according to any one of (1) to (4).

[0023]

(6) According to a fourth aspect of the present invention, there is provided a method of constructing a fire resistant structure, in which the fire resistant structure includes a plurality of protected columns with fireproof coating subjected to a fireproof coating, a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other, and a floor portion partitioned from a slab including a tensile force transmitting member, in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner columns with fireproof coating, in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating, in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape, in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating, the plurality of protected beams with fireproof coating are formed in a

ring shape as a whole, the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction, the method including: a column and beam construction step of constructing the slab, a plurality of beams supporting the slab from below, and columns supporting the plurality of beams; and a coating construction step of subjecting at least a portion of the plurality of beams to the fireproof coating to obtain the plurality of protected beams with fireproof coating so that the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating.

[0024]

(7) According to a fifth aspect of the present invention, there is provided a method of constructing a fire resistant structure, in which the fire resistant structure includes a plurality of protected columns with fireproof coating subjected to a fireproof coating, a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other, and a floor portion partitioned from a slab including a tensile force transmitting member, in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are

defined as protected inner columns with fireproof coating, in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating, in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape, in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating, the plurality of protected beams with fireproof coating and a portion of the plurality of protected columns with fireproof coating are formed in a ring shape as a whole, the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction, the method including: a column and beam construction step of constructing the slab, a plurality of beams supporting the slab from below, and a plurality of columns supporting the plurality of beams; and a coating construction step of supporting the periphery of the floor portion partitioned from the slab by the protected beam with fireproof coating obtained by subjecting the beam to the fireproof coating from below and forming a portion of the plurality of protected columns with fireproof coating obtained by subjecting the plurality of columns to the fireproof coating and the plurality of protected beams with fireproof coating in a ring shape as a whole.

[0025]

(8) According to a sixth aspect of the present invention, there is provided a fire resistant structure including: a plurality of protected columns with fireproof coating subjected to a fireproof coating; a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other; and a floor portion partitioned from a slab including a tensile force transmitting member, in which, in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner column with fireproof coating, in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating, in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape, in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating, the plurality of protected beams with fireproof coating are formed in a ring shape as a whole, the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile

force between end portions of the floor portion in the second intersection direction.

[0026]

(9) The fire resistant structure according to (8) may further include: a protected beam with reduced fireproof coating that has a reduced fireproof coating compared to the protected beam with fireproof coating, is disposed in a region surrounded by the plurality of protected beams with fireproof coating formed in a ring shape, and has an end portion connected to the plurality of protected beams with fireproof coating to support the floor portion from below.

(10) In the fire resistant structure according to (8) or (9), the protected beam with fireproof coating may not be connected to a part of the floor portion other than the periphery.

(11) In the fire resistant structure according to any one of (8) to (10), when the fire resistant structure is heated on the basis of a heating curve defined in ISO 834-11:2014, the maximum value of a deflection of the floor portion at a desired heating time may be less than a threshold K defined by Expression (1).

$$K = (L + l) / 30 \quad (1)$$

Here, L is a length (m) of a first span along the flat surface of the floor portion, and l is a length (m) of a second span which is along the flat surface of the floor portion and intersects the first span.

[0027]

(12) According to a seventh aspect of the present invention, there is provided a fire resistant structure including: a plurality of protected columns with fireproof coating subjected to a fireproof coating; a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other; and a floor portion partitioned from a slab

including a tensile force transmitting member, in which, in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner column with fireproof coating, in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating, in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape, in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating, the plurality of protected beams with fireproof coating and a portion of the plurality of protected columns with fireproof coating are formed in a ring shape as a whole, the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction.

[0028]

According to the configuration described in (1), by performing the structure determination step and the fire resistant specification determination step, the periphery

of the floor portion is set to be supported from below by the plurality of protected beams with fireproof coating which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. At this time, the floor portion is set to be formed in a polygonal shape different from a rectangular shape in a plan view by at least one of the first centerline and the second centerline. In the plan view, all the corner portions of the floor portion are set so as to overlap the plurality of protected columns with fireproof coating, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating. The tensile force transmitting member included in the floor portion is configured to transmit each of the tensile force between the end portions of the floor portion in the first intersection direction and the tensile force between the end portions of the floor portion in the second intersection direction.

If there is a fire, the center portion of the floor portion in a plan view deflects so as to be convex downward due to gravity and the like acting on the floor portion. However, due to a so-called membrane effect, the periphery of the floor portion is supported by the protected beam with fireproof coating. Then, the tensile force transmitting member elongated by the deflection of the floor portion is configured to transmit the tensile forces in the first intersection direction and the second intersection direction, respectively, so that the center portion of the floor portion is supported. Therefore, even if the shape of the floor portion is different from the rectangular shape, the fire resistant structure can be set to maintain a constant fire resistant performance.

[0029]

According to the configuration described in (6), by performing the column and beam construction step and the coating construction step, the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof

coating which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. At this time, the floor portion is formed in a polygonal shape different from a rectangular shape in a plan view by at least one of the first centerline and the second centerline. In the plan view, all the corner portions of the floor portion overlap the plurality of protected columns with fireproof coating, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating. The tensile force transmitting member included in the floor portion is configured to transmit each of the tensile force between the end portions of the floor portion in the first intersection direction and the tensile force between the end portions of the floor portion in the second intersection direction.

If there is a fire, the center portion of the floor portion in a plan view deflects so as to be convex downward due to gravity and the like acting on the floor portion. However, due to the membrane effect, the periphery of the floor portion is supported by the protected beam with fireproof coating. Then, the tensile force transmitting member elongated by the deflection of the floor portion is configured to transmit the tensile forces in the first intersection direction and the second intersection direction, respectively, so that the center portion of the floor portion is supported. Therefore, even if the shape of the floor portion is different from the rectangular shape, the fire resistant structure can maintain a certain fire resistant performance.

[0030]

According to the configuration described in (8), the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. The floor portion is formed in a polygonal shape different from a rectangular shape in a plan view by at least one of the first centerline

and the second centerline. In the plan view, all the corner portions of the floor portion overlap the plurality of protected columns with fireproof coating, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating. The tensile force transmitting member included in the floor portion is configured to transmit each of the tensile force between the end portions of the floor portion in the first intersection direction and the tensile force between the end portions of the floor portion in the second intersection direction.

If there is a fire, the center portion of the floor portion in a plan view deflects so as to be convex downward due to gravity and the like acting on the floor portion. However, due to the membrane effect, the periphery of the floor portion is supported by the protected beam with fireproof coating. Then, the tensile force transmitting member elongated by the deflection of the floor portion is configured to transmit the tensile forces in the first intersection direction and the second intersection direction, respectively, so that the center portion of the floor portion is supported. Therefore, even if the shape of the floor portion is different from the rectangular shape, the fire resistant structure can maintain a certain fire resistant performance.

[0031]

According to the configuration described in (4), by performing the structure determination step and the fire resistant specification determination step, the periphery of the floor portion is set to be supported from below by the plurality of protected beams with fireproof coating and a portion of the plurality of protected columns with fireproof coating which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. At this time, the floor portion is set to be formed in a polygonal shape different from a rectangular shape in a plan view by at least one of the first centerline and the second centerline. In the plan view, all the

corner portions of the floor portion are set so as to overlap the plurality of protected columns with fireproof coating, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating. The tensile force transmitting member included in the floor portion is configured to transmit each of the tensile force between the end portions of the floor portion in the first intersection direction and the tensile force between the end portions of the floor portion in the second intersection direction.

If there is a fire, the center portion of the floor portion in a plan view deflects so as to be convex downward due to gravity and the like acting on the floor portion. However, due to a so-called membrane effect, the periphery of the floor portion is supported by the protected beam with fireproof coating. Then, the tensile force transmitting member elongated by the deflection of the floor portion is configured to transmit the tensile forces in the first intersection direction and the second intersection direction, respectively, so that the center portion of the floor portion is supported. Therefore, even if the shape of the floor portion is different from the rectangular shape, the fire resistant structure can be set to maintain a constant fire resistant performance.

[0032]

According to the configuration described in (7), by performing the column and beam construction step and the coating construction step, the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating and a portion of the plurality of protected columns with fireproof coating which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. At this time, the floor portion is formed in a polygonal shape different from a rectangular shape in a plan view by at least one of the first centerline and the second centerline. In the plan view, all the corner portions of the floor portion

overlap the plurality of protected columns with fireproof coating, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating. The tensile force transmitting member included in the floor portion is configured to transmit each of the tensile force between the end portions of the floor portion in the first intersection direction and the tensile force between the end portions of the floor portion in the second intersection direction.

If there is a fire, the center portion of the floor portion in a plan view deflects so as to be convex downward due to gravity and the like acting on the floor portion. However, due to the membrane effect, the periphery of the floor portion is supported by the protected beam with fireproof coating. Then, the tensile force transmitting member elongated by the deflection of the floor portion is configured to transmit the tensile forces in the first intersection direction and the second intersection direction, respectively, so that the center portion of the floor portion is supported. Therefore, even if the shape of the floor portion is different from the rectangular shape, the fire resistant structure can maintain a certain fire resistant performance.

[0033]

According to the configuration described in (12), the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating and a portion of the plurality of protected columns with fireproof coating which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. The floor portion is formed in a polygonal shape different from a rectangular shape in a plan view by at least one of the first centerline and the second centerline. In the plan view, all the corner portions of the floor portion overlap the plurality of protected columns with fireproof coating, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating. The tensile

force transmitting member included in the floor portion is configured to transmit each of the tensile force between the end portions of the floor portion in the first intersection direction and the tensile force between the end portions of the floor portion in the second intersection direction.

If there is a fire, the center portion of the floor portion in a plan view deflects so as to be convex downward due to gravity and the like acting on the floor portion. However, due to the membrane effect, the periphery of the floor portion is supported by the protected beam with fireproof coating. Then, the tensile force transmitting member elongated by the deflection of the floor portion is configured to transmit the tensile forces in the first intersection direction and the second intersection direction, respectively, so that the center portion of the floor portion is supported. Therefore, even if the shape of the floor portion is different from the rectangular shape, the fire resistant structure can maintain a certain fire resistant performance.

[0034]

According to the configuration described in (2), in general, when the floor portion includes the second floor piece connected to the peripheral portion in addition to the first floor piece, the maximum value of the principal stress of compression generated in the peripheral portion is likely to be relaxed. By performing the determination step assuming that the floor portion includes the first floor piece and the second floor piece, it is possible to easily determine that the maximum value of deflection of the floor portion is equal to or less than the stress threshold in the determination step.

According to the configuration described in (3), for example, in the determination step, there are cases where the principal stress of compression of the floor portion does not exceed the stress threshold. In such a case, the configuration of the fire resistant structure in which the principal stress of compression of the floor portion

does not exceed the stress threshold can be set within a short period of time.

[0035]

According to the configuration described in (5), a fire resistant structure can be designed by the method of designing a fire resistant structure of the present invention. The method of designing a fire resistant structure of the present invention is a method capable of maintaining a certain fire resistant performance while allowing the shape of the floor portion to be a polygonal shape different from a rectangular shape.

[0036]

According to the configuration described in (9), deflection of the floor portion in a normal time when a fire does not occur can be suppressed.

According to the configuration described in (10), restraint of the floor portion if there is a fire by the protected beams with fireproof coating connected to the part of the floor portion other than the periphery is suppressed. Accordingly, the in-plane stress due to compression generated in the floor portion can be reduced.

According to the configuration described in (11), the membrane effect of the floor portion is effectively exhibited. Therefore, the floor portion can be made less likely to deflect downward.

[Effects of the Invention]

[0037]

According to the method of designing a fire resistant structure, the method of constructing a fire resistant structure, and the fire resistant structure of the present invention, a certain fire resistant performance can be maintained while allowing the shape of the floor portion to be a polygonal shape different from a rectangular shape.

[Brief Description of the Drawings]

[0038]

FIG. 1 is a cutaway plan view of a portion of a building in which a fire resistant structure of a first embodiment of the present invention is used.

FIG. 2 is a cross-sectional view taken along the cutting-plane line A1-A1 in FIG. 1.

FIG. 3 is a plan view illustrating a first modification example of a first reinforcing bar of the fire resistant structure.

FIG. 4 is a plan view illustrating a second modification example of the first reinforcing bar of the fire resistant structure.

FIG. 5 is a plan view illustrating a third modification example of the first reinforcing bar of the fire resistant structure.

FIG. 6 is a plan view illustrating a fourth modification example of the first reinforcing bar of the fire resistant structure.

FIG. 7 is a cross-sectional view taken along the cutting-plane line A2-A2 in FIG. 1.

FIG. 8 is a flowchart showing a method of designing a fire resistant structure according to the first embodiment of the present invention.

FIG. 9 is a perspective view illustrating a structure determination step in the method of designing a fire resistant structure.

FIG. 10 is a perspective view illustrating a fire resistant specification determination step in the method of designing a fire resistant structure.

FIG. 11 is a perspective view illustrating a structure determination step in the method of designing a fire resistant structure.

FIG. 12 is a perspective view illustrating a fire resistant specification determination step in the method of designing a fire resistant structure.

FIG. 13 is an exploded perspective view of the fire resistant structure showing

an external force that normally acts on the fire resistant structure.

FIG. 14 is an exploded perspective view of the fire resistant structure showing an external force acting on the fire resistant structure if there is a fire.

FIG. 15 is a flowchart showing a method of constructing a fire resistant structure according to the first embodiment of the present invention.

FIG. 16 is a perspective view schematically illustrating an analysis model of a fire resistant structure of an example.

FIG. 17 is a longitudinal sectional view of an analysis model of a second floor portion in the fire resistant structure of the example.

FIG. 18 is a perspective view schematically illustrating an analysis model of a fire resistant structure of a comparative example.

FIG. 19 is a perspective view schematically illustrating an analysis model of a fire resistant structure of a comparative example.

FIG. 20 is a diagram showing a simulation result of deflection of a floor portion with respect to heating time in the fire resistant structures of the example and the comparative examples.

FIG. 21 is a diagram showing a threshold in a case where the floor portion has a quadrangular shape other than a rectangular shape in a plan view.

FIG. 22 is a diagram showing the principal stress distribution of compression generated in the plane of a second floor portion in the fire resistant structure of the example.

FIG. 23 is a diagram showing the principal stress distribution of tension generated in the plane of the second floor portion in the fire resistant structure of the example.

FIG. 24 is a diagram showing the principal stress distribution of compression

generated in the plane of a first floor portion in the fire resistant structure of the comparative example.

FIG. 25 is a diagram showing the principal stress distribution of tension generated in the plane of the first floor portion in the fire resistant structure of the comparative example.

FIG. 26 is a diagram showing the principal stress distribution of compression generated in the plane of a third floor portion in the fire resistant structure of the comparative example.

FIG. 27 is a diagram showing the principal stress distribution of tension generated in the plane of the third floor portion in the fire resistant structure of the comparative example.

FIG. 28 is a diagram showing changes in the principal stress of compression that occurs in the plane with respect to heating time at corresponding positions of the floor portions in the fire resistant structures of the example and the comparative examples.

FIG. 29 is a perspective view illustrating a portion of a building in which a fire resistant structure of a second embodiment of the present invention is used.

FIG. 30 is a perspective view of a fire resistant structure in the related art.

FIG. 31 is a plan view schematically illustrating a main portion of the fire resistant structure if there is a fire.

FIG. 32 is a cross-sectional view taken along the cutting-plane line A11-A11 in FIG. 31.

FIG. 33 is a perspective view of a building in the related art.

[Embodiments of the Invention]

[0039]

(First Embodiment)

Hereinafter, a building in which a first embodiment of a fire resistant structure according to the present invention is used will be described with reference to FIGS. 1 to 28.

As illustrated in FIGS. 1 and 2, a building 1 includes a plurality of protected columns with fireproof coating 11, a plurality of protected beams with fireproof coating 16, a plurality of protected beams with reduced fireproof coating 26, and a floor (slab) 31. In addition, in FIG. 1 and below, the protected columns with fireproof coating 11 and the protected beams with fireproof coating 16 are hatched.

[0040]

As the protected column with fireproof coating 11, a steel column (H-section steel, cross steel frame, square steel pipe, circular steel pipe, or the like) subjected to a fireproof coating is used. Reinforced concrete (RC), steel reinforced concrete construction (SRC), or concrete filled steel tube (CFT) may be used for the protected column with fireproof coating 11. The fireproof coating in this case will be described together with the protected beam with fireproof coating 16.

As illustrated in FIG. 1, the protected columns with fireproof coating 11 extend along an up-down direction Z. The plurality of protected columns with fireproof coating 11 are disposed side by side at intervals in each of a first intersection direction X and a second intersection direction Y, which are orthogonal to the up-down direction Z and are orthogonal to each other (intersect each other).

Here, in a plan view, among the plurality of protected columns with fireproof coating 11, the protected columns with fireproof coating 11 located in the periphery of the floor 31 are also referred to (defined) as protected outer columns with fireproof coating 11A. Among the plurality of protected columns with fireproof coating 11,

those other than the protected outer columns with fireproof coating 11A are also referred to as protected inner columns with fireproof coating 11B. The protected inner columns with fireproof coating 11B are the protected columns with fireproof coating 11 located at the center portion of the floor 31 in a plan view.

[0041]

Some of the plurality of protected outer columns with fireproof coating 11A (hereinafter, also referred to as protected outer columns with fireproof coating 11A1) are disposed to be shifted from positions in the first intersection direction X toward positions in the second intersection direction Y.

[0042]

As illustrated in FIG. 2, the protected beam with fireproof coating 16 is an H-section steel 18 subjected to a fireproof coating 17. A heat insulating material such as rock wool or glass wool is used for the fireproof coating 17. The fireproof coating 17 is formed on the outer surface of the H-section steel 18 by various methods such as spraying, a painting method, a forming sheet method, and a winding method.

As illustrated in FIGS. 1 and 2, the protected beams with fireproof coating 16 are formed in a straight line shape and are disposed along a horizontal plane. Both end portions of the protected beam with fireproof coating 16 are connected to another protected beam with fireproof coating 16 and the protected column with fireproof coating 11, respectively. The protected beams with fireproof coating 16 connect the plurality of protected columns with fireproof coating 11.

As illustrated in FIG. 1, protected beams with fireproof coating 16A, which are some of the plurality of protected beams with fireproof coating 16, extend along the first intersection direction X. Protected beams with fireproof coating 16B, which some of the plurality of protected beams with fireproof coating 16, extend along the second

intersection direction Y. Protected beams with fireproof coating 16C, which are the remainder of the plurality of protected beams with fireproof coating 16, have end portions respectively connected to the protected beams with fireproof coating 16A and 16B and are inclined with respect to each of the first intersection direction X and the second intersection direction Y.

[0043]

For example, the plurality of protected beams with fireproof coating 16 including the protected beams with fireproof coating 16C, the protected beams with fireproof coating 16A, and the two protected beams with fireproof coating 16B constitute a protected beam assembly with fireproof coating 16D. The protected beam assembly with fireproof coating 16D is formed in a ring shape (angular ring shape) which is a trapezoidal frame in a plan view as a whole.

The plurality of protected beams with fireproof coating 16 are supported from below by the plurality of protected columns with fireproof coating 11.

RC and SRC may be used for the protected beam with fireproof coating 16.

[0044]

The protected beam with reduced fireproof coating 26 is a beam having a reduced fireproof coating compared to the protected beams with fireproof coating 16. The protected beam with reduced fireproof coating 26 may be an H-section steel that is not subjected to a fireproof coating. The protected beam with reduced fireproof coating 26 may be an H-section steel subjected to a slight fireproof coating, although the fireproof coating is reduced compared to the protected beams with fireproof coating 16.

For example, the thickness of the fireproof coating such as rock wool in the protected beams with fireproof coating 16 is set based on “Sprayed rock wool coated

fire resistant structure, construction quality management guidelines (Rock Wool Association Japan, spraying subcommittee). In a case where the protected beams with fireproof coating 16 are required to be fire resistant for one hour, the thickness of the fireproof coating is set to 25 mm. Similarly, in a case where the protected beams with fireproof coating 16 are required to be fire resistant for two hours, the thickness of the fireproof coating is set to 45 mm, and in a case where the protected beams with fireproof coating 16 are required to be fire resistant for three hours, the thickness of the fireproof coating is set to 65 mm. In this case, the thickness of the fireproof coating on the protected beam with reduced fireproof coating 26 is set to about 1/10 to 1/2 of the thickness of the fireproof coating on the protected beams with fireproof coating 16 according to the corresponding fire resistant performance.

The protected beams with reduced fireproof coating 26 are disposed in a region R1 or the like surrounded by the protected beam assembly with fireproof coating 16D.

Both ends of the protected beam with reduced fireproof coating 26 are connected to the plurality of protected beams with fireproof coating 16.

[0045]

As illustrated in FIGS. 1 and 2, the floor 31 is a so-called composite slab, and is supported from below by the plurality of protected beams with fireproof coating 16 and the plurality of protected beams with reduced fireproof coating 26. As illustrated in FIG. 2, the floor 31 includes a deck plate (tensile force transmitting member) 32, a concrete 33, and reinforcing bars (tensile force transmitting members) 34. The floor 31 does not have to include the deck plate 32 and the concrete 33. The floor 31 does not have to include the reinforcing bars 34 and concrete 33. The tensile force transmitting members included in the floor 31 are not limited to the deck plate 32 and the reinforcing bars 34.

For example, the deck plate 32 is formed by bending a steel plate. The deck plate 32 is disposed on the plurality of protected beams with fireproof coating 16 and the plurality of protected beams with reduced fireproof coating 26.

The concrete 33 is formed in a plate shape having the up-down direction Z as the thickness direction. In the concrete 33, protrusions 33a protruding downward to correspond to the shape of the deck plate 32 are formed. For example, the width of the protrusion 33a gradually decreases downward in the first intersection direction X.

[0046]

The reinforcing bars 34 are buried in the concrete 33. The reinforcing bars 34 include a plurality of first reinforcing bars 35 and a plurality of second reinforcing bars 36. In FIG. 2, only one first reinforcing bar 35 is shown.

Each first reinforcing bar 35 extends along the first intersection direction X. Each first reinforcing bar 35 transmits tensile force between end portions of the concrete 33 (floor 31) in the first intersection direction X. In other words, each first reinforcing bar 35 extends between a first end portion of the concrete 33 in the first intersection direction X and a second end portion of the concrete 33 opposite to the first end portion in the first intersection direction X. Each first reinforcing bar 35 transmits tensile force acting between the first end portion and the second end portion of the concrete 33 between the first end portion and the second end portion of the concrete 33. The plurality of first reinforcing bars 35 are disposed at intervals in the second intersection direction Y.

Similarly, each second reinforcing bar 36 extends along the second intersection direction Y. Each second reinforcing bar 36 transmits tensile force between end portions of the concrete 33 in the second intersection direction Y. The plurality of second reinforcing bars 36 are disposed at intervals in the first intersection direction X.

[0047]

The directions in which the reinforcing bars 35 and 36 extend may be different from the directions in which the plurality of protected columns with fireproof coating 11 are disposed side by side at intervals.

In the following description, the details of the configurations of the first reinforcing bar 35 and the second reinforcing bar 36 will be described by taking the first reinforcing bar 35 as an example.

[0048]

The first reinforcing bar 35 is not particularly limited as long as it can transmit tensile force between the end portions of the concrete 33 in the first intersection direction X. The first reinforcing bar 35 may be formed of one reinforcing bar between the first end portion and the second end portion of the concrete 33 in the first intersection direction X but may be configured as follows. Round steel bar, deformed steel bar, mesh, or the like is used for the first reinforcing bar 35.

As in a first modification example illustrated in FIG. 3, a first reinforcing bar 35A may include reinforcing bar pieces 37a and 37b and a connection reinforcing bar 37c that connects end portions of the reinforcing bar pieces 37a and 37b. The reinforcing bar pieces 37a and 37b and the connection reinforcing bar 37c are formed of the same material as the first reinforcing bar 35.

The end portion of the reinforcing bar piece 37a and a first end portion of the connection reinforcing bar 37c are connected by a weld 38 formed by welding. The end portion of the reinforcing bar piece 37b and a second end portion of the connection reinforcing bar 37c opposite to the first end portion are connected by a weld 38.

[0049]

As in a second modification example illustrated in FIG. 4, a first reinforcing

bar 35B may include the reinforcing bar piece 37a and the reinforcing bar piece 37b. The end portion of the reinforcing bar piece 37a and the end portion of the reinforcing bar piece 37b are connected by the weld 38.

As in a third modification example illustrated in FIG. 5, a first reinforcing bar 35C may include the reinforcing bar pieces 37a and 37b and an annealing wire (wire) 39. The reinforcing bar piece 37a and the reinforcing bar piece 37b are tied by the annealing wire 39 in a state of being overlapped by a predetermined required length. The reinforcing bar piece 37a and the reinforcing bar piece 37 are connected to each other by bonding.

As in a fourth modification example illustrated in FIG. 6, a first reinforcing bar 35D may include the reinforcing bar pieces 37a and 37b and a mechanical joint 40. The mechanical joint 40 is a coupling or the like. The mechanical joint 40 connects the reinforcing bar piece 37a and the reinforcing bar piece 37b by sandwiching the end portions of the reinforcing bar pieces 37a and 37b.

The second reinforcing bar 36 is configured in the same manner as the first reinforcing bar 35.

[0050]

As illustrated in FIG. 7, a bent portion 35a that is bent downward may be formed at the end portion of the first reinforcing bar 35 in the first intersection direction X. The bent portion 35a extends downward from the outside of the second reinforcing bar 36 disposed on the outermost side in the first intersection direction X among the plurality of second reinforcing bars 36.

The number of the first reinforcing bars 35 included in the reinforcing bars 34 is not particularly limited, and may be one. The number of the second reinforcing bars 36 included in the reinforcing bars 34 is not particularly limited, and may be one.

The first intersection direction X and the second intersection direction Y are directions that intersect each other in a flat surface 31a which is the upper surface of the floor 31.

[0051]

As illustrated in FIG. 7, the floor 31 is fixed to the plurality of protected beams with fireproof coating 16 and the plurality of protected beam with reduced fireproof coating 26 by studs 46 or the like provided on the upper surfaces of the plurality of protected beams with fireproof coating 16 and the plurality of protected beams with reduced fireproof coating 26.

[0052]

Here, with reference to FIG. 7, the positional relationship between the end portions of the concrete 33 and the first reinforcing bar 35 in the first intersection direction X and the protected beam with fireproof coating 16 will be described. The H-section steel 18 of the protected beam with fireproof coating 16 is configured by connecting an upper flange 18a and a lower flange 18b to each other via a web 18c.

Here, the end edge of the upper flange 18a of the H-section steel 18 on the center portion side of the floor 31 in a plan view is referred to as an end edge 18a1. The end edge of the upper flange 18a opposite to the end edge 18a1 is referred to as an end edge 18a2. The center of the web 18c in the first intersection direction X is referred to as a plate center 18c1.

For example, the end of the concrete 33 in the first intersection direction X coincides with the end edge 18a2.

In the first intersection direction X, the end of the first reinforcing bar 35 in the first intersection direction X reaches the end edge 18a1 from the center portion side of the floor 31 in a plan view. It is more preferable that the end portion of the first

reinforcing bar 35 reaches the plate center 18c1 in the first intersection direction X.

[0053]

The same applies to the end portion of the second reinforcing bar 36 in the second intersection direction Y.

The positional relationship between the first reinforcing bar 35 and the second reinforcing bar 36 of the floor 31 and the protected beam with fireproof coating 16 is the same as the positional relationship between the first reinforcing bar 35 and the second reinforcing bar 36 included in floor portions 31A and 31B partitioned from the floor 31, which will be described later, and the protected beam with fireproof coating 16.

[0054]

Here, first centerlines C6 and second centerlines C7 are defined with reference to FIG. 1. The first centerline C6 is a line (line segment) that passes through the center of the protected inner column with fireproof coating 11B and the center of the protected outer column with fireproof coating 11A in a plan view and reaches the periphery of the floor 31. The center of the column referred to here is, for example, the center of gravity of the column in a plan view. A first end of the first centerline C6 is located at the center of the protected inner column with fireproof coating 11B. A second end of the first centerline C6, which is opposite to the first end, is located in the periphery of the floor 31. The first centerline C6 passes through the center of the protected outer column with fireproof coating 11A.

The second centerline C7 is a line (line segment) passing through the centers of the protected inner column with fireproof coating 11B in a plan view. A first end of the second centerline C7 is located at the center of one of a pair of protected inner columns with fireproof coating 11B. A second end of the second centerline C7, which is opposite to the first end, is located at the center of the other of the pair of protected

inner columns with fireproof coating 11B.

[0055]

In the present embodiment, the floor 31 is partitioned into a plurality of the floor portions 31A and 31B by at least one of the first centerline C6 and the second centerline C7 and the periphery of the floor 31. The floor portions 31A and 31B are portions of the floor 31, which are partitioned from the floor 31. The floor 31 may be partitioned by at least one of the first centerline C6 and the second centerline C7.

Specifically, the floor 31 is partitioned into the first floor portion 31A by two first centerlines C6 and one second centerline C7. The floor 31 is partitioned into the second floor portion (floor portion) 31B by two first centerlines C6. The floor portions 31A and 31B are parts of the floor 31 partitioned by at least one of the centerlines C6 and C7.

Here, two protected beams with fireproof coating 16A and two protected beams with fireproof coating 16B disposed in the periphery of the first floor portion 31A are referred to as a protected beam assembly with fireproof coating 16E. The protected beam assembly with fireproof coating 16E is formed in a ring shape in a plan view as a whole.

[0056]

The first floor portion 31A is partitioned in a rectangular shape in a plan view to correspond to the protected beam assembly with fireproof coating 16E. The periphery of the first floor portion 31A is supported from below by the protected beam assembly with fireproof coating 16E over the whole circumference. In a plan view, all the corner portions of the first floor portion 31A are disposed so as to overlap the plurality of protected columns with fireproof coating 11. Overlapping of the corner portions and the plurality of protected columns with fireproof coating 11 means that at

least some of the corner portions are disposed in a region occupied by at least one of the plurality of protected columns with fireproof coating.

All the corner portions of the first floor portion 31A are supported from below by any of the plurality of protected columns with fireproof coating 11.

The first floor portion 31A, four protected columns with fireproof coating 11, the protected beam assembly with fireproof coating 16E, and the protected beam with reduced fireproof coating 26A supporting the first floor portion 31A among the plurality of protected beams with reduced fireproof coating 26 constitute a first fire resistant structure 51A.

[0057]

On the other hand, the second floor portion 31B is formed in a polygonal shape different from a rectangular shape in a plan view to correspond to the protected beam assembly with fireproof coating 16D. More specifically, the polygonal shape is a trapezoidal shape. The reinforcing bars 34 included in the second floor portion 31B transmit each of tensile force between end portions of the second floor portion 31B in the first intersection direction X and tensile force between end portions of the second floor portion 31B in the second intersection direction Y.

The second floor portion 31B, four protected columns with fireproof coating 11, the protected beam assembly with fireproof coating 16D, and the protected beams with reduced fireproof coating 26B supporting the second floor portion 31B among the plurality of protected beams with reduced fireproof coating 26 constitute a second fire resistant structure (fire resistant structure) 51B. In FIG. 2, the boundary between the first fire resistant structure 51A and the second fire resistant structure 51B is shown by a solid line.

[0058]

The periphery of the second floor portion 31B is supported from below by the protected beam assembly with fireproof coating 16D over the whole circumference. In a plan view, all the corner portions included in the second floor portion 31B are disposed so as to overlap the plurality of protected columns with fireproof coating 11. That is, all the corner portions of the second floor portion 31B are supported from below by any of the plurality of protected columns with fireproof coating 11.

In this example, the second fire resistant structure 51B includes three protected beams with reduced fireproof coating 26B.

No other protected columns with fireproof coating 11 are disposed inside the four protected columns with fireproof coating 11 included in the second fire resistant structure 51B. The protected beams with fireproof coating 16 are not connected to parts of the second floor portion 31B other than the periphery. All the beams disposed inside the protected beams with fireproof coating 16A, 16B, and 16C connected in the periphery of the second floor portion 31B over the whole circumference are the protected beams with reduced fireproof coating 26. The protected beams with reduced fireproof coating 26 supports the second floor portion 31B from below.

[0059]

Here, a heating curve defined in ISO 834-11:2014 (hereinafter, abbreviated to ISO 834) is also simply referred to as a heating curve below. The second fire resistant structure 51B is preferably configured so that when the second fire resistant structure 51B is heated based on the heating curve, the maximum value of deflection of the second floor portion 31B at a desired heating time is less than a threshold K (m) defined by Expression (6).

$$K = (L + l) / 30 \quad (6)$$

Here, L is the length (m) of the second floor portion 31B in the first

intersection direction X (first span). l is the length (m) of the second floor portion 31B in the second intersection direction Y (second span). L and l are the lengths of the second floor portion 31B in directions along the flat surface 31a.

The threshold K is the deflection limit value of the floor described in Non-Patent Document 1 described above.

The first span is not limited to the length in the first intersection direction X, and may be the length of the second floor portion 31B in a direction within the flat surface 31a (direction along the flat surface 31a). The second span is not limited to the length in the second intersection direction Y, and may be the length of the second floor portion 31B in a direction within the flat surface 31a, which is orthogonal to (intersects) the first span.

[0060]

In a case where the second floor portion is not rectangular in a plan view, L is the length of the first span along the flat surface of the second floor portion, and l is the length of the second span which is along the flat surface of the floor portion and intersects the first span. At this time, it is preferable to set the directions of the first and second spans so that the threshold K obtained by Expression (6) becomes smaller. That is, the maximum value of deflection of the second floor portion 31B is preferably less than the threshold K obtained by Expression (6) regardless of the directions of the first and second spans. By setting the threshold K as described above, damage to the second floor portion can be evaluated on the safe side.

The threshold is not limited thereto.

[0061]

Next, a method of designing a fire resistant structure for designing the second fire resistant structure 51B configured as described above (hereinafter, also abbreviated

to a design method) will be described. FIG. 8 is a flowchart showing a design method S of the present embodiment. In the design method S of the present embodiment, a design method for designing the second fire resistant structure 51B in the building 1 will be described. The design method S is preferably used for, for example, a newly constructed second fire resistant structure 51B and an existing second fire resistant structure 51B.

First, in step S1 shown in FIG. 8, a stress threshold is determined in advance. For example, the stress threshold is determined based on the design criteria of the material used for the second fire resistant structure 51B and the like.

When step S1 is ended, the step proceeds to step S3.

[0062]

Next, in a structure determination step (step S3), by performing a known structural calculation, as illustrated in FIG. 9, the disposition of the floor 31, a plurality of beams 56, and a plurality of columns 57 in a structure 52 is determined. In FIG. 9 and the like, the floor 31 is shown by a two-dot chain line.

The beam 56 is a beam from which the fireproof coating is removed from the protected beam with fireproof coating 16 and the protected beam with reduced fireproof coating 26. The plurality of beams 56 support the floor 31 from below. The column 57 is a column from which the fireproof coating is removed from the protected column with fireproof coating 11. The plurality of columns 57 support the plurality of beams 56.

In this example, the structure 52 includes one more column 57 (protected column with fireproof coating 11) (hereinafter, also referred to as column 57A) than the second fire resistant structure 51B. The column 57A is disposed so as to overlap the corner portions of a predetermined rectangular shape in a plan view together with the

three columns 57 among the plurality of columns 57 provided in the structure 52 in advance. The column 57A is disposed near the end of the beam 56 included in the plurality of protected beam with reduced fireproof coating 26.

In the structure determination step S3, for example, the specifications and disposition of the plurality of beams 56 and the plurality of columns 57 are determined from the weight of the floor 31 and the load acting on the floor 31.

When the structure determination step S3 is ended, the step proceeds to step S5.

[0063]

Next, in a fire resistant specification determination step (step S5), when a second floor portion 31B1 is partitioned from the floor 31, setting is performed as follows. As illustrated in FIG. 10, setting is performed so that the periphery of the second floor portion 31B1 partitioned from the floor 31 is supported from below by the plurality of protected beams with fireproof coating 16 obtained by subjecting the beams 56 to a fireproof coating. Partitioning of the floor 31 is performed using the first centerlines C6. The plurality of protected beams with fireproof coating 16 are formed in a ring shape as a whole. Setting is performed so that all the corner portions included in the second floor portion 31B1 are disposed overlapping the plurality of protected columns with fireproof coating 11.

In this example, first, in the fire resistant specification determination step S5, a first floor piece 31C partitioned into a rectangular shape (predetermined shape) in a plan view is referred to as the second floor portion 31B1. At this time, the second fire resistant structure 51B1 is designed by subjecting at least some of the plurality of beams 56 to a fireproof coating so that a membrane effect of the second floor portion 31B1 is exhibited if there is a fire. The membrane effect mentioned here means an effect of

holding a floor portion on which a load acts, in a shape in which the center portion of the floor portion deflects to be convex downward by protected beams with fireproof coating and tensile force transmitting members if there is a fire.

In this example, setting is performed so that the periphery of the second floor portion 31B1 is supported from below by the plurality of protected beams with fireproof coating 16 formed in a ring shape as a whole. Setting is performed so that all the corner portions included in the second floor portion 31B1 are disposed overlapping the plurality of protected columns with fireproof coating 11. By subjecting a portion of the beam 56 in the longitudinal direction to a fireproof coating, the protected beam with fireproof coating 16B and a beam piece 56A are formed from the beam 56.

When the fire resistant specification determination step S5 is ended, the step proceeds to step S7.

[0064]

Next, in a determination step (step S7), it is determined whether or not the principal stress of compression of the second floor portion 31B1 exceeds the stress threshold. Whether or not the principal stress of compression of the second floor portion 31B1 exceeds the stress threshold can be determined by performing a known simulation or the like. When it is determined in the determination step S7 that the principal stress of compression of the second floor portion 31B1 exceeds the stress threshold (YES), the step proceeds to the structure determination step S3. On the other hand, when it is determined that the principal stress of compression of the second floor portion 31B1 does not exceed the stress threshold (is equal to or less than the stress threshold) (NO), the entire steps of the design method S are ended. At this time, the second fire resistant structure 51B1 is designed to the above specification.

In this example, it is assumed that the maximum value of the principal stress of

compression occurs in a peripheral portion 31C1 which is a portion of the periphery of the second floor portion 31B1. Then, it is assumed that the maximum value of the principal stress of this compression is determined to exceed the stress threshold. In this case, after the determination step S7, the step proceeds to the structure determination step S3.

[0065]

In the structure determination step S3 to which the determination step S7 proceeds, the disposition of the floor 31, the plurality of beams 56, and the plurality of columns 57 in a structure 52A is determined as illustrated in FIG. 11. The structure 52A does not include column 57A in the structure 52.

Next, in the fire resistant specification determination step S5, as illustrated in FIG. 12, it is assumed that the second floor portion 31B is partitioned into a shape including the first floor piece 31C and a second floor piece 31D. The second floor piece 31D is connected to the peripheral portion 31C1 of the first floor piece 31C. In a plan view, the second floor piece 31D has a triangular shape. In a plan view, the second floor portion 31B has a trapezoidal shape.

In the fire resistant specification determination step S5, setting is performed so that the periphery of the second floor portion 31B partitioned from the floor 31 is supported from below by the plurality of protected beams with fireproof coating 16 obtained by subjecting the beams 56 to a fireproof coating. The plurality of protected beams with fireproof coating 16 are formed in a ring shape as a whole. Setting is performed so that all the corner portions provided by the second floor portion 31B are disposed overlapping the plurality of protected columns with fireproof coating 11.

[0066]

Next, in the determination step S7, it is determined whether or not the principal

stress of compression of the second floor portion 31B exceeds the stress threshold. In general, if a floor portion includes a second floor piece connected to the peripheral portion thereof, the maximum value of the principal stress of compression generated in the peripheral portion is likely to be relaxed. In this example, in the determination step S7, it is determined that the principal stress of compression of the second floor portion 31B does not exceed the stress threshold (NO), and the entire steps of the design method S are ended. The second fire resistant structure 51B is a fire resistant structure designed by the design method S.

[0067]

In the design method S of the present embodiment, when a determination of YES is made in the determination step S7, the step may proceed to the fire resistant specification determination step S5.

In addition, in the design method of the present embodiment, in the fire resistant specification determination step, it may be assumed that the second floor portion has a polygonal shape different from a rectangular shape in a plan view. Even in this case, if it is determined in the determination step that the principal stress of compression of the floor portion does not exceed the stress threshold (NO), the entire steps of the design method are ended.

[0068]

Here, a form in which the second floor portion 31B and the like deflect before and after a fire due to the membrane effect will be schematically described.

FIG. 13 illustrates an exploded perspective view of the second fire resistant structure 51B in a normal time when no fire has occurred. In FIG. 13 and FIG. 14 described later, the second fire resistant structure 51B is shown in a simplified manner. Specifically, FIGS. 13 and 14 show only one protected beam with reduced fireproof

coating 26 of the second fire resistant structure 51B.

In the normal time illustrated in FIG. 13, a downward external force F1 acts on the second floor portion 31B, the protected beam with reduced fireproof coating 26, and the like due to gravity, static load, and the like acting on the second floor portion 31B, the protected beam with reduced fireproof coating 26, and the like.

On the other hand, if there is a fire, as illustrated in FIG. 14, the center portion of the second floor portion 31B in a plan view deflects so as to be convex downward. However, due to the so-called membrane effect, the periphery of the second floor portion 31B is supported by the plurality of protected beams with fireproof coating 16 formed in a ring shape as a whole. The first reinforcing bar 35 elongated by the deflection of the second floor portion 31B transmits a tensile force F2 in the first intersection direction X. The second reinforcing bar 36 elongated by the deflection of the second floor portion 31B transmits a tensile force F3 in the second intersection direction Y. That is, the second floor portion 31B resists the gravity and the like acting on the second floor portion 31B by the tensile forces F2 and F3.

Therefore, the center portion of the second floor portion 31B is supported by the plurality of protected beams with fireproof coating 16 and the reinforcing bars 35 and 36 in each of the first intersection direction X and the second intersection direction Y.

[0069]

At this time, a tensile region R5 and a compressive region R6 are formed in the second floor portion 31B. The compressive region R6 is hatched in FIG. 14. In the tensile region R5, the second floor portion 31B is pulled along the deflected flat surface 31a. In the compressive region R6, the second floor portion 31B is compressed along the deflected flat surface 31a.

The tensile region R5 is formed in the center portion of the second floor portion 31B in a plan view. The compressive region R6 is formed around the tensile region R5.

[0070]

The membrane effect that occurs in the second fire resistant structure 51B if there is a fire is an effect that the reinforcing bars 34 resist the tensile forces F2 and F3. On the other hand, in Patent Document 1, the robustness generated in the fire resistant structure if there is a fire is an effect of resisting the bending moment B1 by concrete and reinforcing bars.

As described above, the second fire resistant structure 51B of the present embodiment and the fire resistant structure of Patent Document 1 have different effects if there is a fire.

[0071]

Next, a method of constructing a fire resistant structure for constructing the second fire resistant structure 51B (manufacturing method, hereinafter, also abbreviated to a construction method) will be described. FIG. 15 is a flowchart showing a construction method S20 of the present embodiment. While each step of the design method S is only set and not used for actual construction, each step of the construction method S20 is different in that it is used for actual construction. The construction method S20 is preferably used for, for example, a newly constructed second fire resistant structure 51B.

In this construction method S20, a column and beam construction step S21 and a coating construction step S23 are performed.

In the column and beam construction step S21, the floor 31, the plurality of beams 56, and the plurality of columns 57 are constructed.

In the coating construction step S23, at least some of the plurality of beams 56 are subjected to a fireproof coating to obtain the plurality of protected beams with fireproof coating 16, so that the periphery of the second floor portion 31B is supported from below by the plurality of protected beams with fireproof coating 16.

As described above, all the steps of the construction method S20 are ended, and the second fire resistant structure 51B is constructed.

[0072]

In a method of designing a fire resistant structure disclosed in Non-Patent Document 1, a floor portion is designed to have a rectangular shape in a plan view. Therefore, those skilled in the art who have seen Non-Patent Document 1 try to achieve a membrane effect on the rectangular shape.

[0073]

Contrary to this, according to the design method S of the present embodiment, by performing the structure determination step S3 and the fire resistant specification determination step S5, the periphery of the second floor portion 31B is set to be supported from below by the plurality of protected beams with fireproof coating 16 which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. At this time, the second floor portion 31B is set to be formed in a trapezoidal shape in a plan view by the two first centerlines C6. In a plan view, all the corner portions of the second floor portion 31B are set so as to overlap the plurality of protected columns with fireproof coating 11, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating 11. The reinforcing bars 34 included in the second floor portion 31B transmit each of the tensile force F2 between the end portions of the second floor portion 31B in the first intersection direction X and the tensile force F3 between the end portions of the second

floor portion 31B in the second intersection direction Y.

If there is a fire, the center portion of the second floor portion 31B in a plan view deflects so as to be convex downward due to gravity and the like acting on the second floor portion 31B. However, due to the membrane effect, the periphery of the second floor portion 31B is supported by the protected beams with fireproof coating 16. Then, the reinforcing bars 34 elongated by the deflection of the second floor portion 31B transmit the tensile forces F2 and F3 in the first intersection direction X and the second intersection direction Y, respectively, so that the center portion of the second floor portion 31B is supported. Therefore, even if the shape of the second floor portion 31B is trapezoidal, the second fire resistant structure 51B can be set to maintain a certain fire resistant performance.

[0074]

In addition, according to the construction method S20 of the present embodiment, by performing the column and beam construction step S21 and the coating construction step S23, the periphery of the second floor portion 31B is supported from below by the plurality of protected beams with fireproof coating 16 which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. At this time, the second floor portion 31B is formed in a trapezoidal shape in a plan view by the two first centerlines C6. In a plan view, all the corner portions of the second floor portion 31B overlap the plurality of protected columns with fireproof coating 11, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating 11. The reinforcing bars 34 included in the second floor portion 31B transmit each of the tensile force F2 between the end portions of the second floor portion 31B in the first intersection direction X and the tensile force F3 between the end portions of the second floor portion 31B in the second intersection

direction Y.

If there is a fire, the center portion of the second floor portion 31B in a plan view deflects so as to be convex downward due to gravity and the like acting on the second floor portion 31B. However, due to the membrane effect, the periphery of the second floor portion 31B is supported by the protected beams with fireproof coating 16. Then, the reinforcing bars 34 elongated by the deflection of the second floor portion 31B transmit the tensile forces F2 and F3 in the first intersection direction X and the second intersection direction Y, respectively, so that the center portion of the second floor portion 31B is supported. Therefore, even if the shape of the second floor portion 31B is trapezoidal, the second fire resistant structure 51B can maintain a certain fire resistant performance.

[0075]

In addition, according to the second fire resistant structure 51B of the present embodiment, the periphery of the second floor portion 31B is supported from below by the plurality of protected beams with fireproof coating 16 formed in a ring shape which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. The second floor portion 31B is formed in a trapezoidal shape in a plan view by the two first centerlines C6. In a plan view, all the corner portions of the second floor portion 31B overlap the plurality of protected columns with fireproof coating 11, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating 11. The reinforcing bars 34 included in the second floor portion 31B transmit each of the tensile force F2 between the end portions of the second floor portion 31B in the first intersection direction X and the tensile force F3 between the end portions of the second floor portion 31B in the second intersection direction Y.

If there is a fire, the center portion of the second floor portion 31B in a plan view deflects so as to be convex downward due to gravity and the like acting on the second floor portion 31B. However, due to the membrane effect, the periphery of the second floor portion 31B is supported by the protected beams with fireproof coating 16. Then, the reinforcing bars 34 elongated by the deflection of the second floor portion 31B transmit the tensile forces F2 and F3 in the first intersection direction X and the second intersection direction Y, respectively, so that the center portion of the second floor portion 31B is supported. Therefore, even if the shape of the second floor portion 31B is trapezoidal, the second fire resistant structure 51B can maintain a certain fire resistant performance.

[0076]

The second fire resistant structure 51B includes the protected beams with reduced fireproof coating 26. Accordingly, deflection of the second floor portion 31B in a normal time when a fire does not occur can be suppressed.

The protected beams with fireproof coating 16 are not connected to parts of the second floor portion 31B other than the periphery. Therefore, restraint of the second floor portion 31B if there is a fire by the protected beams with fireproof coating 16 connected to the parts of the second floor portion 31B other than the periphery is suppressed. Accordingly, the in-plane stress due to compression generated in the second floor portion 31B can be reduced.

The maximum value of deflection of the second floor portion 31B does not exceed the threshold K. Accordingly, the membrane effect of the second floor portion 31B is effectively exhibited. Therefore, the second floor portion 31B can be made less likely to deflect downward.

[0077]

The determination step S7 is performed with the first floor piece 31C as the second floor portion 31B1. In the determination step S7, when the maximum value of the principal stress of compression occurs in the peripheral portion 31C1 and it is determined that the maximum value of the principal stress of compression exceeds the stress threshold, it is assumed that the second floor portion 31B is partitioned into a shape including the first floor piece 31C and the second floor piece 31D. Then, the structure determination step S3 to the determination step S7 are performed.

In general, when a floor portion includes, in addition to a first floor piece, a second floor piece connected to the peripheral portion thereof, the maximum value of the principal stress of compression generated in the peripheral portion is likely to be relaxed. By performing the determination step S7 assuming that the second floor portion 31B includes the first floor piece 31C and the second floor piece 31D, it is possible to easily determine that the maximum value of deflection of the second floor portion 31B is equal to or less than the stress threshold in the determination step S7.

[0078]

Assuming that the second floor portion has a trapezoidal shape in a plan view in the fire resistant specification determination step, the determination step is performed. For example, in the determination step, there may be cases where the principal stress of compression of the second floor portion does exceed the stress threshold. In such a case, the configuration of the fire resistant structure in which the principal stress of compression of the second floor portion does not exceed the stress threshold can be set within a short period of time.

The second fire resistant structure 51B is a fire resistant structure designed by the design method S. Accordingly, the second fire resistant structure 51B can be designed by the design method S of the present embodiment. The design method S is

a method capable of maintaining a certain fire resistant performance while allowing the shape of the second floor portion to be a polygonal shape different from a rectangular shape.

[0079]

(Simulation Result)

Here, the results of evaluating the fire resistant performance of fire resistant structures of examples and comparative examples by a simulation will be described.

FIG. 16 schematically illustrates a perspective view of an analysis model of the fire resistant structure 51B of an example. In FIG. 16, the second floor portion 31B is not illustrated. The fire resistant structure 51B corresponds to the above-described second fire resistant structure 51B.

The protected beams with fireproof coating 16A, 16B, and 16C were H-section steels formed of SS400 material, which is a rolled steel material for a general structure, and having a cross-sectional shape of $350 \times 175 \times 7 \times 11$ mm.

Of the three protected beams with reduced fireproof coating 26B, the protected beam with reduced fireproof coating 26B1 disposed closest to the protected beam with fireproof coating 16C was an H-section steel formed of SS400 material and having a cross-sectional shape of $350 \times 175 \times 7 \times 11$ mm. Of the three protected beams with reduced fireproof coating 26B, the protected beams with reduced fireproof coating 26B2 other than the protected beam with reduced fireproof coating 26B1 were H-section steels formed of SS400 material and having a cross-sectional shape of $300 \times 150 \times 6.5 \times 9$ mm.

[0080]

The pitch in the first intersection direction X between a pair of protected beams with fireproof coating 16B was set to 9 m. The pitch in the second intersection

direction Y between the three protected beams with reduced fireproof coating 26B was set to 3 m. The pitch in the second intersection direction Y between the protected beam with fireproof coating 16A and the protected beam with reduced fireproof coating 26B2 adjacent to the protected beam with fireproof coating 16A in the second intersection direction Y was set to 3 m. The pitch in the second intersection direction Y between the joint portion between the protected beam with fireproof coating 16B, which is the longer one of the pair of protected beams with fireproof coating 16B, and the protected beam with fireproof coating 16C, and the protected beam with reduced fireproof coating 26B1 was set to 3 m.

The positions of the joint portions between the protected beam with fireproof coating 16A and the protected beams with fireproof coating 16B were set to be held in the first intersection direction X, the second intersection direction Y, and the up-down direction Z. The joint portion was set to be rotatable around an axis parallel to each of the first intersection direction X, the second intersection direction Y, and the up-down direction Z. The same constraint conditions were applied to the joint portion between the protected beam with fireproof coating 16C and the protected beam with fireproof coating 16B.

[0081]

FIG. 17 illustrates a longitudinal sectional view of an analysis model of the second floor portion 31B in the fire resistant structure 51B of the embodiment.

In the concrete 33, the length of the lower end of the protrusion 33a in the first intersection direction X was set to 125 mm. The lower end of the protrusion 33a was set to be disposed at a position closer to the center of the protrusion 33a by 25 mm on both sides in the first intersection direction X than the upper end of the protrusion 33a. The concrete 33 was set to extend from the protrusion 33a on both sides in the first

intersection direction X by 62.5 mm.

The length of the protrusion 33a in the up-down direction Z was set to 50 mm. The distance from the upper end of the reinforcing bar 34 to the upper surface of the concrete 33 (the cover thickness of the concrete 33 with respect to the reinforcing bar 34) was set to 30 mm. The thickness of the second floor portion 31B was set to 130 mm.

The second floor portion 31B did not include the deck plate 32. That is, the deck plate 32 was not set in the analysis model of the second floor portion 31B.

[0082]

A plurality of concretes 33 configured as described above were set to be arranged at a pitch of 300 mm in the first intersection direction X. The concrete 33 was disposed so that the protrusion 33a extended along the second intersection direction Y.

The concrete 33 was normal concrete (NC) and set to have a water content of 10%. A design standard strength F_c of the concrete 33 was set to 24 N/mm^2 (Newton per square millimeter).

The reinforcing bar 34 was a deformed steel bar (SD295A) defined in JIS G 3112:2010, steel bars for concrete reinforcement, and set to have an outer diameter of 6 mm. In the reinforcing bars 34, the plurality of second reinforcing bars 36 were set to be disposed at a pitch of 150 mm in the first intersection direction X. The plurality of first reinforcing bars 35 were set to be disposed at a pitch of 150 mm in the second intersection direction Y.

[0083]

On the other hand, FIG. 18 schematically illustrates a perspective view of an analysis model of a fire resistant structure 51A of a comparative example. In FIG. 18,

the first floor portion was not illustrated. The fire resistant structure 51A corresponds to the configuration of the first fire resistant structure 51A described above, which includes two protected beams with reduced fireproof coating 26A.

The protected beams with fireproof coating 16A and 16B of the fire resistant structure 51A were set to have the same configuration as the protected beams with fireproof coating 16A, 16B, and 16C of the fire resistant structure 41B. That is, the protected beams with fireproof coating 16A and 16B were H-section steels formed of SS400 material and having a cross-sectional shape of $350 \times 175 \times 7 \times 11$ mm. The protected beam with reduced fireproof coating 26A of the fire resistant structure 51A was set to have the same configuration as the protected beam with reduced fireproof coating 26B2 of the fire resistant structure 51B.

The pitch in the first intersection direction X between a pair of protected beams with fireproof coating 16B was set to 9 m. The pitch in the second intersection direction Y between the two protected beams with reduced fireproof coating 26A was set to 3 m. The pitch in the second intersection direction Y between the protected beam with fireproof coating 16A and the protected beam with reduced fireproof coating 26A adjacent to the protected beam with fireproof coating 16A in the second intersection direction Y was set to 3 m.

The positions of the joint portions between the protected beam with fireproof coating 16A and the protected beams with fireproof coating 16B were set to be held in the first intersection direction X, the second intersection direction Y, and the up-down direction Z. The joint portion was set to be rotatable around an axis parallel to each of the first intersection direction X, the second intersection direction Y, and the up-down direction Z.

The shape of the longitudinal section of the first floor portion was set to be the

same as the shape of the longitudinal section of the second floor portion 31B.

[0084]

FIG. 19 schematically illustrates a perspective view of an analysis model of a fire resistant structure 51C of a comparative example. In FIG. 19, a third floor portion supported by the protected beams with fireproof coating 16A, 16B, 16C, and the like was not illustrated.

The fire resistant structure 51C is set to have a protected beam with fireproof coating 16G by subjecting the protected beam with reduced fireproof coating 26B1 to a fireproof coating in the fire resistant structure 51B of the example.

The third floor portion has the same configuration as the second floor portion 31B of the fire resistant structure 51B of the example.

In the third floor portion, a floor portion whose periphery is supported by the protected beams with fireproof coating 16A, 16B, and 16G over the whole circumference has a rectangular shape in a plan view.

[0085]

When the fire resistant structures 51B of the example and the fire resistant structures 51A and 51C of the comparative examples were heated based on the heating curve defined in ISO 834, the deflection of the floor portions, the in-plane stress of the floor portions, and the like with respect to the heating time were obtained by simulations.

In the simulations, the temperature of the fire resistant structure rises due to the heating of the fire resistant structure supported under the above-mentioned constraint conditions. Depending on the temperature, the fire resistant structure elongates and stress acts in the fire resistant structure, so that the stiffness and strength of the fire resistant structure change. It is considered that if there is a fire, the protected columns

with fireproof coating 11, the protected beams with fireproof coating 16, and the reinforcing bars 34 produce predetermined stiffness and strength, while the protected beams with reduced fireproof coating 26 lose their stiffness and strength.

[0086]

The simulation result of the deflection of the floor portions is shown in FIG. 20. In FIG. 20, the horizontal axis represents the heating time (minutes, elapsed time from the start of heating). The vertical axis represents the deflection (mm) at substantially the center of the floor portions of the fire resistant structures 51B, 51A, and 51C.

FIG. 16 shows a position P1 at substantially the center of the second floor portion 31B. Similarly, FIG. 18 shows a position P2 at substantially the center of the first floor portion, and FIG. 19 shows a position P3 at substantially the center of the third floor portion.

[0087]

In FIG. 20, the L1 indicated by the solid line and marked with O represents the deflection at the position P1 of the second floor portion 31B in the fire resistant structure 51B of the example. The L2 indicated by the dotted line and marked with Δ represents the deflection at the position P2 of the first floor portion in the fire resistant structure 51A of the comparative example. The L3 indicated by the dot dashed line and marked with $\square$ represents the deflection at the position P3 of the third floor portion in the fire resistant structure 51C of the comparative example.

It is known that when the deflection at, for example, the position P1 of the second floor portion 31B becomes sufficiently large and the second floor portion 31B collapses, the deflection at the position P1 of the second floor portion 31B increases sharply with respect to the heating time to the degree indicated by the two-dot chain line

L4 in FIG. 20.

According to this simulation result, it was found that as the heating time increased, the deflection at substantially the center of the second floor portion 31B, the first floor portion, and the third floor portion gradually increased. It was found that the deflection at the position P3 of the third floor portion was larger than the deflection at the position P2 of the first floor portion for a predetermined heating time from 0 minutes to 30 minutes. It was found that the deflection at the position P1 of the second floor portion 31B was larger than the deflection at the position P3 of the third floor portion.

[0088]

Here, the deflection limit value of the floor described in Non-Patent Document 1 will be described. The threshold K (m), which is the deflection limit value of the floor, is defined as in Expression (6).

[0089]

As illustrated in FIG. 21, in a case where a floor portion 66 has a quadrangular shape other than the rectangular shape in a plan view, the inventors consider that the threshold K is obtained as follows, for example.

That is, the floor portion 66 has two pairs of opposite sides (a pair of sides 66a and 66b and a pair of sides 66c and 66d). The length of the line connecting the midpoint of the side 66a and the midpoint of the side 66b is referred to as the length L of a first span. The length of the line connecting the midpoint of the side 66c and the midpoint of the side 66d is referred to as the length l of a second span. Using these lengths L and l , the threshold K is obtained from Expression (6).

[0090]

A method of obtaining the threshold K in a case where the floor portion 66 has

a quadrangular shape other than the rectangular shape is used in a case where a floor portion has a rectangular shape to obtain the value of the threshold K. The value of the threshold K in this case corresponds to the value of the threshold K in the case where the floor portion represented by Expression (6) in Non-Patent Document 1 has a rectangular shape. That is, the method of obtaining the threshold K proposed by the inventors extends the method of obtaining the threshold K represented by Expression (6) in Non-Patent Document 1 even to the case where the floor portion has a quadrangular shape other than the rectangular shape.

The inventors propose a method of obtaining the value of the threshold K as a method of obtaining the value of the threshold K which is an extension of Expression (6) of Non-Patent Document 1.

[0091]

As illustrated in FIG. 16, the lengths of the fire resistant structure 51B of the example are defined, and the second floor portion 31B has a quadrangular shape other than a rectangular shape in a plan view. The lengths L and l of the second floor portion 31B are 10.5 m and 9.12 m according to Expressions (8) and (9).

$$(12 + 9) / 2 = 10.5 \quad (8)$$

$$\sqrt{(9^2 + 1.5^2)} = 9.12 \quad (9)$$

Therefore, the threshold K of the fire resistant structure 51B is 0.654 m, that is, 654 mm according to Expression (10).

$$K = (10.5 + 9.12) / 30 = 0.654 \dots (10)$$

The line corresponding to 654 mm is shown in FIG. 20 as the solid line L6. That is, it is determined that the second floor portion 31B is held without collapsing until the value of the line L1 representing the fire resistant structure 51B of the example reaches at least the value of the line L6.

[0092]

As illustrated in FIG. 19, since the lengths of the fire resistant structure 51C of the comparative example are defined, the floor portion of the third floor portion whose periphery is supported by the protected beams with fireproof coating 16A, 16B, and 16G over the whole circumference has a square shape with a side of 9 m in a plan view. As illustrated in FIG. 18, since the lengths of the fire resistant structure 51A of the comparative example are defined, the first floor portion has a square shape with a side of 9 m in a plan view. Therefore, the threshold K of the fire resistant structures 51A and 51C is 0.60 m, that is, 600 mm according to Expression (12).

$$K = (9 + 9) / 30 = 0.60 \quad (12)$$

The line corresponding to 600 mm is shown in FIG. 20 as the dotted line L7. That is, it is determined that the first floor portion and the third floor portion are held without collapsing until the value of the line L2 representing the fire resistant structure 51A of the comparative example and the value of the line L3 representing the fire resistant structure 51C of the comparative example reach at least the value of the line L7.

[0093]

According to these simulation results, it was found that in a case where the heating time is about 30 minutes, the maximum value of deflection of the second floor portion 31B of the fire resistant structure 51B of the example is less than the threshold K that is 654 mm due to the so-called membrane effect. It was found that the maximum value of deflection of the first floor portion of the fire resistant structure 51A and the third floor portion of the fire resistant structure 51C of the comparative example is less than the threshold K that is 600 mm.

Furthermore, it was found that the ratio of the maximum value of deflection of

the fire resistant structure 51B to the threshold K that is 654 mm and the ratio of the maximum value of deflection of the fire resistant structures 51A and 51C to the threshold K that is 600 mm are similar to each other. It was found that the fire resistant performance of the fire resistant structures 51B of the examples is maintained at the same level as the fire resistant performances of the fire resistant structures 51B and 51C of the comparative examples.

[0094]

In addition to 30 minutes, a desired time such as one hour or two hours is used as the heating time based on the fire resistant performance defined by the Building Standards Act of Japan.

[0095]

FIGS. 22 to 27 show simulation results of the in-plane stress (stress generated in a plane having the up-down direction Z as the normal line) of the second floor portion 31B of the fire resistant structure 51B of the example and the first floor portion and the third floor portion of the fire resistant structures 51A and 51C of the comparative examples at a time point when the heating time is 30 minutes.

FIGS. 22, 24, and 26 show the principal stress distribution of compression that occurs in the plane of the floor portion, and FIGS. 23, 25, and 27 show the principal stress distribution of tension that occurs in the plane of the floor portion.

In any of FIGS. 22 to 27, the direction of the principal stress is represented as the length direction of a line. In each of the principal stress of compression and the principal stress of tension, the length of the line is shown to increase as the principal stress increases.

It is considered that if the principal stress of compression of the floor portion exceeds a predetermined value, there is a possibility that the floor portion may collapse.

[0096]

The fire resistant structure 51B of the example does not have the protected beam with fireproof coating 16G for the fire resistant structure 51C of the comparative example, and the protected beam with fireproof coating 16 is not connected to a portion other than the periphery of the second floor portion 31B. Therefore, it was found that if there is a fire, the position (peripheral portion) of the protected beam with reduced fireproof coating 26B1 is not restrained by the beam. Then, it was found that the compressive stress and the tensile stress due to compression at the position where the protected beam with reduced fireproof coating 26B1 is disposed is reduced (relaxed).

The compressive stress and the tensile stress of the second floor portion 31B of the fire resistant structure 51B of the example are equal to or larger than the compressive stress and the tensile stress of the first floor portion of the fire resistant structure 51A of the comparative example.

[0097]

FIG. 28 shows changes in the principal stress of compression that occurs in the plane with respect to the heating time at the corresponding positions of the second floor portion 31B of the fire resistant structure 51B of the example and the third floor portion of the fire resistant structure 51C of the comparative example. The corresponding position in the second floor portion 31B of the fire resistant structure 51B of the example is shown in FIG. 22 as the position P5. The corresponding position in the third floor portion of the fire resistant structure 51C of the comparative example is shown in FIG. 26 as the position P6.

In FIG. 28, the horizontal axis represents the heating time, and the vertical axis represents the principal stress of compression (kN/m: kilonewton per meter) generated in the plane.

The line L11 indicated by the solid line and marked with O represents the principal stress of compression generated in the plane of the fire resistant structure 51B of the example. The line L13 indicated by the solid line and marked with □ represents the principal stress of compression generated in the plane of the fire resistant structure 51C of the comparative example.

In either case, the principal stress of compression generated in the plane increases with the elapse of heating time. However, it was found that regardless of the heating time, the principal stress of compression generated in the plane at the position P5 of the second floor portion 31B of the fire resistant structure 51B of the example is smaller than the principal stress of compression generated in the plane at the position P6 of the third floor portion of the fire resistant structure 51C of the comparative example.

[0098]

In general, as the outer shape of the fire resistant structure becomes smaller, each of the deflection limit value of the floor portion described in Non-Patent Document 1 and the maximum value of deflection of the floor portion obtained by the simulation become smaller. However, the degree to which the value becomes smaller is larger in the maximum value of deflection of the floor portion than the deflection limit value of the floor portion. Therefore, as the outer shape of the fire resistant structure becomes smaller, it becomes difficult for the maximum value of deflection of the floor portion to exceed the deflection limit value of the floor portion, and it becomes difficult to determine that the floor portion collapses.

By combining the fire resistant structure 51B of the example, the fire resistant structure 51A of the comparative example, and the like, it is possible to deal with buildings having various shapes.

[0099]

(Second Embodiment)

Next, a second embodiment of the present invention will be described with reference to FIG. 29 and FIGS. 8 and 15 described above. Like elements the same as those of the embodiment are denoted by like reference numerals, the description thereof will be omitted, and only differences will be described.

As illustrated in FIG. 29, a second fire resistant structure 71B of the present embodiment includes four protected columns with fireproof coating 72 instead of the four protected columns with fireproof coating 11 of the second fire resistant structure 51B of the first embodiment. In FIG. 29, any part of the building other than the second fire resistant structure 71B is not illustrated.

[0100]

Each protected column with fireproof coating 72 differs from the protected column with fireproof coating 11 only in the length in the up-down direction Z. Each protected column with fireproof coating 72 is longer than the protected column with fireproof coating 11. Each protected column with fireproof coating 72 extends upward beyond the second floor portion 31B.

In the present embodiment, each end portion of the protected beam with fireproof coating 16 is connected to the protected column with fireproof coating 72. Here, a part of the protected column with fireproof coating 72 connected to the protected beam with fireproof coating 16 (a portion of the protected column with fireproof coating) is referred to as a column piece 72a.

The plurality of protected beams with fireproof coating 16 and a plurality of the column pieces 72a are formed in a ring shape as a whole. The periphery of the second floor portion 31B is supported from below by the plurality of protected beams with fireproof coating 16.

[0101]

In this example, the four protected beams with fireproof coating 16 and the two column pieces 72a are formed in a ring shape as a whole. However, the number of protected beams with fireproof coating 16 and the number of column pieces 72a formed in a ring shape as a whole are not particularly limited.

[0102]

Next, a design method for designing the second fire resistant structure 71B configured as described above will be described. FIG. 8 is a flowchart showing a design method S30 of the present embodiment. The difference between the design method S30 and the design method S of the first embodiment is that a fire resistant specification determination step S31 is performed in place of the fire resistant specification determination step S5.

In the fire resistant specification determination step S31, setting is performed so that the periphery of the second floor portion 31B partitioned from the floor 31 is supported from below by the plurality of protected beams with fireproof coating 16. Furthermore, setting is performed so that the plurality of protected beams with fireproof coating 16 and the plurality of column pieces 72a are formed in a ring shape as a whole.

[0103]

Next, a construction method for constructing the second fire resistant structure 71B will be described. FIG. 15 is a flowchart showing a construction method S40 of the present embodiment. The difference between the construction method S40 and the construction method S20 of the first embodiment is that a coating construction step S41 is performed in place of the coating construction step S23.

In the coating construction step S41, the periphery of the second floor portion 31B partitioned from the floor 31 is supported from below by the plurality of protected

beams with fireproof coating 16. Furthermore, the plurality of protected beams with fireproof coating 16 and the plurality of column pieces 72a are formed in a ring shape as a whole.

[0104]

As described above, according to the design method S30 of the present embodiment, by performing the structure determination step S3 and the fire resistant specification determination step S31, the periphery of the second floor portion 31B is set to be supported from below by the plurality of protected beams with fireproof coating 16 and the plurality of column pieces 72a which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. At this time, the second floor portion 31B is set to be formed in a trapezoidal shape in a plan view by the two first centerlines C6. In a plan view, all the corner portions of the second floor portion 31B are set so as to overlap the plurality of protected columns with fireproof coating 11, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating 11. The reinforcing bars 34 included in the second floor portion 31B transmit each of the tensile force F2 between the end portions of the second floor portion 31B in the first intersection direction X and the tensile force F3 between the end portions of the second floor portion 31B in the second intersection direction Y.

If there is a fire, the center portion of the second floor portion 31B in a plan view deflects so as to be convex downward due to gravity and the like acting on the second floor portion 31B. However, due to the membrane effect, the periphery of the second floor portion 31B is supported by the protected beams with fireproof coating 16. Then, the reinforcing bars 34 elongated by the deflection of the second floor portion 31B transmit the tensile forces F2 and F3 in the first intersection direction X and the

second intersection direction Y, respectively, so that the center portion of the second floor portion 31B is supported. Therefore, even if the shape of the second floor portion 31B is trapezoidal, the second fire resistant structure 71B can be set to maintain a certain fire resistant performance.

[0105]

In addition, according to the construction method S40 of the present embodiment, by performing the column and beam construction step S21 and the coating construction step S41, the periphery of the second floor portion 31B is supported from below by the plurality of protected beams with fireproof coating 16 and the plurality of column pieces 72a which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. At this time, the second floor portion 31B is formed in a trapezoidal shape in a plan view by the two first centerlines C6. In a plan view, all the corner portions of the second floor portion 31B overlap the plurality of protected columns with fireproof coating 11, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating 11. The reinforcing bars 34 included in the second floor portion 31B transmit each of the tensile force F2 between the end portions of the second floor portion 31B in the first intersection direction X and the tensile force F3 between the end portions of the second floor portion 31B in the second intersection direction Y.

If there is a fire, the center portion of the second floor portion 31B in a plan view deflects so as to be convex downward due to gravity and the like acting on the second floor portion 31B. However, due to the membrane effect, the periphery of the second floor portion 31B is supported by the protected beams with fireproof coating 16. Then, the reinforcing bars 34 elongated by the deflection of the second floor portion 31B transmit the tensile forces F2 and F3 in the first intersection direction X and the

second intersection direction Y, respectively, so that the center portion of the second floor portion 31B is supported. Therefore, even if the shape of the second floor portion 31B is trapezoidal, the second fire resistant structure 71B can maintain a certain fire resistant performance.

[0106]

In addition, according to the second fire resistant structure 71B of the present embodiment, the periphery of the second floor portion 31B is supported from below by the plurality of protected beams with fireproof coating 16 and the plurality of column pieces 72a which can maintain a certain stiffness and strength even if there is a fire and are formed in a ring shape as a whole. The second floor portion 31B is formed in a trapezoidal shape in a plan view by the two first centerlines C6. In a plan view, all the corner portions of the second floor portion 31B overlap the plurality of protected columns with fireproof coating 11, whereby all the corner portions are supported by the plurality of protected columns with fireproof coating 11. The reinforcing bars 34 included in the second floor portion 31B transmit each of the tensile force F2 between the end portions of the second floor portion 31B in the first intersection direction X and the tensile force F3 between the end portions of the second floor portion 31B in the second intersection direction Y.

If there is a fire, the center portion of the second floor portion 31B in a plan view deflects so as to be convex downward due to gravity and the like acting on the second floor portion 31B. However, due to the membrane effect, the periphery of the second floor portion 31B is supported by the protected beams with fireproof coating 16. Then, the reinforcing bars 34 elongated by the deflection of the second floor portion 31B transmit the tensile forces F2 and F3 in the first intersection direction X and the second intersection direction Y, respectively, so that the center portion of the second

floor portion 31B is supported. Therefore, even if the shape of the second floor portion 31B is trapezoidal, the second fire resistant structure 71B can maintain a certain fire resistant performance.

[0107]

While the first and second embodiments of the present invention have been described in detail with reference to the drawings, the specific configuration is not limited to these embodiments, and changes, combinations, deletions, and the like of configurations within a range that does not deviate from the gist of the present invention are also included. Furthermore, it is needless to say that the respective configurations described in the embodiments can be used in combination as appropriate.

For example, the second fire resistant structures 31B and 71B of the first embodiment and the second embodiment do not have to include the protected beam with reduced fireproof coating 26. The protected beam with fireproof coating 16 may be connected to a portion other than the periphery of the second floor portion 31B.

In a plan view, the second floor portion may have a triangular shape or a polygonal shape having five or more corner portions (corners).

In the design methods S and S30, the determination step S7 does not have to be performed.

[Industrial Applicability]

[0108]

The method of designing a fire resistant structure, the method of constructing a fire resistant structure, and the fire resistant structure of the present disclosure can be suitably used as a fire resistant structure and a design method and a construction method thereof capable of maintaining a certain fire resistant performance while allowing the shape of a floor portion to be a polygonal shape different from a rectangular shape.

[Brief Description of the Reference Symbols]

[0109]

- 11, 72 Protected column with fireproof coating
- 11A Protected outer column with fireproof coating
- 11B Protected inner column with fireproof coating
- 16 Protected beam with fireproof coating
- 26 Protected beam with reduced fireproof coating
- 31 Floor (slab)
- 31a Flat surface
- 31B Second floor portion (floor portion)
- 31C First floor piece
- 31C1 Peripheral portion
- 31D Second floor piece
- 32 Deck plate (tensile force transmitting member)
- 34 Reinforcing bar (tensile force transmitting member)
- 51B, 51C, 71B Second fire resistant structure (fire resistant structure)
- 72a Column piece (portion of protected column with fireproof coating)
- C6 First centerline
- C7 Second centerline
- S, S30 Design method (method of designing fire resistant structure)
- S3 Structure determination step
- S5, S31 Fire resistant specification determination step
- S7 Determination step
- S20, S40 Construction method (method of constructing fire resistant structure)

S21 Column and beam construction step

S23, S41 Coating construction step

X First intersection direction

Y Second intersection direction

1. A method of designing a fire resistant structure,
in which the fire resistant structure includes
 - a plurality of protected columns with fireproof coating subjected to a fireproof coating,
 - a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other, and
 - a floor portion partitioned from a slab including a tensile force transmitting member,

in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner columns with fireproof coating,

in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating,

in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape,

in the plan view, all corner portions included in the floor portion are disposed

so as to overlap the plurality of protected columns with fireproof coating,

the plurality of protected beams with fireproof coating are formed in a ring shape as a whole,

the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and

when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction,

the method comprising:

a structure determination step of determining a disposition of the slab, a plurality of beams supporting the slab from below, and columns supporting the plurality of beams by performing a structural calculation; and

a fire resistant specification determination step of performing setting the periphery of the floor portion partitioned from the slab is supported from below by the protected beam with fireproof coating obtained by subjecting the beam to the fireproof coating.

2. The method of designing a fire resistant structure according to claim 1, wherein, in the fire resistant specification determination step, a first floor piece partitioned into a predetermined shape in the plan view is used as the floor portion, a determination step of determining whether or not a principal stress of compression of the floor portion exceeds a predetermined stress threshold is performed, and

when it is determined in the determination step that a maximum value of the principal stress of the compression occurs in a peripheral portion that is a portion of the periphery of the floor portion and the maximum value of the principal stress of the compression exceeds the predetermined stress threshold,

at least the fire resistant specification determination step is performed assuming that the floor portion is partitioned into a shape including the first floor piece and a second floor piece connected to the peripheral portion of the first floor piece and the floor portion has a polygonal shape different from a rectangular shape in the plan view, and the determination step is further performed.

3. The method of designing a fire resistant structure according to claim 1, wherein, in the fire resistant specification determination step, it is assumed that the floor portion has a polygonal shape different from a rectangular shape in the plan view, and

a determination step of determining whether or not a principal stress of compression of the floor portion exceeds a predetermined stress threshold is performed.

4. A method of designing a fire resistant structure, in which the fire resistant structure includes

a plurality of protected columns with fireproof coating subjected to a fireproof coating,

a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other, and

a floor portion partitioned from a slab including a tensile force

transmitting member,

in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner columns with fireproof coating,

in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating,

in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape,

in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating,

the plurality of protected beams with fireproof coating and a portion of the plurality of protected columns with fireproof coating are formed in a ring shape as a whole,

the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and

when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between

end portions of the floor portion in the second intersection direction,

the method comprising:

a structure determination step of determining a disposition of the slab, a plurality of beams supporting the slab from below, and a plurality of columns supporting the plurality of beams by performing a structural calculation; and

a fire resistant specification determination step of performing setting so that the periphery of the floor portion partitioned from the slab is supported from below by the protected beam with fireproof coating obtained by subjecting the beam to the fireproof coating and a portion of the plurality of protected columns with fireproof coating obtained by subjecting the plurality of columns to the fireproof coating and the plurality of protected beams with fireproof coating are formed in a ring shape as a whole.

5. A fire resistant structure designed by the method of designing a fire resistant structure according to any one of claims 1 to 4.

6. A method of constructing a fire resistant structure,

in which the fire resistant structure includes

a plurality of protected columns with fireproof coating subjected to a fireproof coating,

a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other, and

a floor portion partitioned from a slab including a tensile force transmitting member,

in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner columns with fireproof coating,

in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating,

in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape,

in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating,

the plurality of protected beams with fireproof coating are formed in a ring shape as a whole,

the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and

when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction,

the method comprising:

a column and beam construction step of constructing the slab, a plurality of beams supporting the slab from below, and columns supporting the plurality of beams; and

a coating construction step of subjecting at least some of the plurality of beams to the fireproof coating to obtain the plurality of protected beams with fireproof coating so that the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating.

7. A method of constructing a fire resistant structure,
in which the fire resistant structure includes

a plurality of protected columns with fireproof coating subjected to a fireproof coating,

a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other, and

a floor portion partitioned from a slab including a tensile force transmitting member,

in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner columns with fireproof coating,

in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with

fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating,

in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape,

in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating,

the plurality of protected beams with fireproof coating and a portion of the plurality of protected columns with fireproof coating are formed in a ring shape as a whole,

the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and

when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction, the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction,

the method comprising:

a column and beam construction step of constructing the slab, a plurality of beams supporting the slab from below, and a plurality of columns supporting the plurality of beams; and

a coating construction step of supporting the periphery of the floor portion partitioned from the slab by the protected beam with fireproof coating obtained by subjecting the beam to the fireproof coating from below and forming a portion of the plurality of protected columns with fireproof coating obtained by subjecting the

plurality of columns to the fireproof coating and the plurality of protected beams with fireproof coating in a ring shape as a whole.

8. A fire resistant structure comprising:

a plurality of protected columns with fireproof coating subjected to a fireproof coating;

a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other; and

a floor portion partitioned from a slab including a tensile force transmitting member,

wherein, in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner column with fireproof coating,

in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the centers of the protected inner columns with fireproof coating,

in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape,

in the plan view, all corner portions included in the floor portion are disposed

so as to overlap the plurality of protected columns with fireproof coating,

the plurality of protected beams with fireproof coating are formed in a ring shape as a whole,

the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and

when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction,

the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction.

9. The fire resistant structure according to claim 8, further comprising:

a protected beam with reduced fireproof coating that has a reduced fireproof coating compared to the protected beam with fireproof coating, is disposed in a region surrounded by the plurality of protected beams with fireproof coating formed in a ring shape, and has an end portion connected to the plurality of protected beams with fireproof coating to support the floor portion from below.

10. The fire resistant structure according to claim 8 or 9,

wherein the protected beam with fireproof coating is not connected to a part of the floor portion other than the periphery.

11. The fire resistant structure according to any one of claims 8 to 10,

when the fire resistant structure is heated on the basis of a heating curve

defined in ISO 834-11:2014, a maximum value of a deflection of the floor portion at a desired heating time is less than a threshold K defined by Expression (1),

$$K = (L + l) / 30 \quad (1)$$

where L is a length (m) of a first span along the flat surface of the floor portion, and l is a length (m) of a second span which is along the flat surface of the floor portion and intersects the first span.

12. A fire resistant structure comprising:

a plurality of protected columns with fireproof coating subjected to a fireproof coating;

a plurality of protected beams with fireproof coating that are subjected to a fireproof coating and connect the plurality of protected columns with fireproof coating to each other; and

a floor portion partitioned from a slab including a tensile force transmitting member,

wherein, in a plan view, when the protected columns with fireproof coating located in a periphery of the slab among the plurality of protected columns with fireproof coating are defined as protected outer columns with fireproof coating, and the protected columns with fireproof coating other than the protected outer columns with fireproof coating among the plurality of protected columns with fireproof coating are defined as protected inner column with fireproof coating,

in the plan view, the floor portion is a part of the slab partitioned by at least one of a first centerline which passes through a center of the protected inner column with fireproof coating and a center of the protected outer column with fireproof coating and reaches the periphery of the slab, and a second centerline which passes through the

centers of the protected inner columns with fireproof coating,

in the plan view, the floor portion is formed in a polygonal shape different from a rectangular shape,

in the plan view, all corner portions included in the floor portion are disposed so as to overlap the plurality of protected columns with fireproof coating,

the plurality of protected beams with fireproof coating and a portion of the plurality of protected columns with fireproof coating are formed in a ring shape as a whole,

the periphery of the floor portion is supported from below by the plurality of protected beams with fireproof coating, and

when directions intersecting each other in a flat surface of the floor portion are defined as a first intersection direction and a second intersection direction,

the tensile force transmitting member is configured to transmit each of tensile force between end portions of the floor portion in the first intersection direction and tensile force between end portions of the floor portion in the second intersection direction.