fire protection planning report

BUILDING CONSTRUCTION INFORMATION FROM THE CONCRETE AND MASONRY INDUSTRIES

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The Decline of Fire Limits and the Need for Improved Conflagration Protection in the Model Building Codes

Part I - A Perspective on Fire Limits

INTRODUCTION

Fire limits, also referred to as fire districts or fire zones, were established years ago to protect against large destructive fires (conflagrations) in built-up areas. As the use of fire limits diminished or disappeared altogether, the gap in fire protection was to be filled through the implementation of appropriate building code provisions. An examination of today's model building codes shows that these replacement provisions have not adequately satisfied this objective. The deficiency lies in the failure of codes to properly address the exterior ignition of buildings due to radiant heat energy or direct flame contact. Recommendations correlating requirements of set-back distances and opening protection for buildings having either combustible exterior walls, or exterior walls with combustible veneers are proposed in this report as corrective action.

BACKGROUND

Historically, there are many cases of cities having been virtually consumed by fire. Some cities have experienced more than one such devastating fire. Almost everyone is familiar with the Chicago fire of 1871, and the fire that followed the great San Francisco earthquake in 1906. Less renowned, but equally disastrous fires occurred in London in 1136 and 1666, and in Baltimore in 1873 and 1904. The list could continue, but that would serve no useful purpose other

Combustible exterior walls and cladding are more conducive to conflagration development than are buildings of noncombustible construction. Note the presence of three separate ignition points on the combustible facade.

than to more graphically illustrate the fire problem that confronted earlier generations.

In response to these disastrous fires, cities began to adopt construction standards intended to reduce the likelihood of conflagrations. These standards, in early years, focused on requiring masonry chimneys and prohibiting thatched roofs. While these requirements reduced the risk of a chimney fire from extending beyond the chimney, and helped decrease the potential ignition of a highly combustible roofing system from flying brands, they did little to reduce the consequences of accidental fires originating from either within or outside the building. If a fire advanced beyond the limited capabilities of the manual fire suppression forces of that time, widespread destruction generally followed.

Laws next focused on regulating other aspects of building construction, in particular, exterior walls. Cities began to mandate that exterior walls and party walls be constructed of masonry. Presumably, this would allow the building of fire origin to be consumed while the exterior walls remained standing. Conceptually, this would limit fire spread and prevent conflagrations that were once commonplace. Zone boundaries were set up to designate areas where these requirements would apply.

As building codes became more prevalent, fire zones were transcribed into the codes and, in fact, were included in the first (1905) edition of the *Building Code*.* By the middle of the 20th century, the three model codes, which were being used as the basis for an increasing number of local building codes, also contained such provisions.

THE DECLINE OF FIRE LIMITS

Fire limits were developed on the basis that they would be applied to those areas with highly congested business, commercial, manufacturing, and warehousing uses, or areas in which such uses were developing. "Highly congested" was typically defined by an area consisting of at least two contiguous blocks, exclusive of streets, having at least 50% of its land area built up. In some cases there were provisions for two such districts. The first district being described as above, and the second possessing identical characteristics, except that residential use areas could be included within the boundaries. In the late 1970's and mid 1980's, however, fire limits provisions were deleted from two of the three model codes. Today, only the *Standard Building Code*[3] (SBC) retains fire limit provisions, but the chapter containing them does not have to be mandatorily adopted with the rest of the code.

Many reasons can be cited for the demise of fire limits. First and possibly foremost is the fact that many jurisdictions misapplied the provisions to areas that were much less densely developed than was contemplated. The reasons for this misapplication are many; ranging from a lack of understanding of the intent, to overtly forcing a more fire resistive type of construction motivated by the prospect of better insurance rates. Large-scale migration of city dwellers to the suburbs after World War II is likely to have also played a role. During the 1970's, commerce and industry had followed this trend, and shopping centers and business parks with large open areas replaced contiguous rows of buildings that were popular and typical of the earlier city model. Thus, when the building concentration in cities diminished, the risk of a conflagration decreased along with the need for fire zones.

As fire protection engineering principles were becoming more widely applied in building design, it was argued that preventing building-to-building fire spread should be a goal of the code for the entire jurisdiction, and not just in those areas designated as fire limits. In theory, if principles of fire protection were applied across the board, fire limits would not be needed. The result was a de-emphasis of fire limits in favor of utilizing other means to protect against conflagrations. Some of the mechanisms that were left in place to fill the protection gap included restrictions on types of construction, height and area limits, fire resistance rating and opening protection requirements for exterior walls, etc.

While there have been valid arguments to eliminate fire limits, adequate safeguards have not been substituted in codes to protect against building-to-building fire spread that can lead to a conflagration. The remainder of this report will focus on this issue and provide recommendations for correcting the deficiencies.

Part II - The Need for Improved Conflagration Protection in Model Building Codes

A SCIENTIFIC LOOK AT PREVENTING BUILDING-TO-BUILDING FIRE SPREAD

Some of the oldest laws regulating the construction of buildings required exterior walls to be of masonry. This represents a classical specification provision. As new, alternative materials were developed, however, a method had to be devised to permit the use of these materials. At the same time, it was necessary to provide reasonable assurance that fire containment would be at least equivalent to that provided by masonry.

With the development of the ASTM E119 test method, although originally applicable only to fire testing of floor assemblies, came the answer. This permitted performance type provisions requiring minimum hourly fire resistance ratings in lieu of specifications requiring masonry walls. In general, the required fire resistance ratings were a function of the type of construction and the distance to lot lines.

* The *Building Code*[1] was first published in 1905 by the National Board of Fire Underwriters, now known as the American Insurance Association (AIA). Subsequently, it was abandoned by the AIA and the title was given to the Building Officials and Code Administrators International, Inc. (BOCA). In 1984, BOCA renamed its *BOCA Basic Building Code* to the current *BOCA/National Building Code*[2] (BNBC).

To prevent building-to-building fire spread via the exterior walls of a building, the wall must posses the following attributes:

1 It must withstand the burnout of the building contents, while continuing to support its own weight and other gravity loads that are dependent upon the wall for support.
2 It must not conduct enough heat through the wall to ignite combustibles attached to the opposite side of the wall, or located in close proximity to the wall.
3 It must retain its integrity so that cracks or fissures do not develop sufficiently wide to allow hot gases or flames to pass through the wall and ignite combustibles attached to the opposite side or in close proximity to the wall.
4 Openings, such as doors and windows, must be limited so that radiant energy is not sufficient to ignite combustibles attached to the exterior of an adjacent building.
5 When combustible cladding is attached to the exterior wall, the building must be located a sufficient distance from a neighboring building to insure that radiant energy from a fire in the neighboring building will not ignite the cladding.

Items 1 through 3 above are evaluated by subjecting a wall to the ASTM E119[4] standard fire test to determine its fire endurance classification time period, or its fire resistance rating. The rating required should be related to the estimated time that it will take an uncontrolled fire to consume the combustible contents of the building. Obviously, this will vary from one building to another. Although it has been recognized for many years that the "fire load equals fire duration" relationship developed by the National Bureau of Standards in the 1920's is no longer valid for estimating fire intensity, the relationship may still be useful in correlating the required fire resistance ratings of exterior walls with the anticipated fire load of various use groups or occupancy classifications. A more detailed discussion of when fire resistance rated walls should be required is presented later in this report.

Items 4 and 5 take into account the protection of buildings against a radiant heat exposure. The first consideration is to limit the area of openings in exterior walls (windows and doors) of the exposing building so that the radiant energy emitted through them during a fire is not sufficient to ignite combustible cladding on adjacent buildings.

The amount of radiation being received at a point (the target) from a burning building is determined from the following formula:

$$I_r = I_e \cdot \phi \qquad \textbf{Eq. 1}$$

where I_r = radiation being received
I_e = radiation being emitted
ϕ = configuration factor

For these calculation purposes, it is generally assumed that the radiation being emitted, I_e, will be at least 179 kW/m^2. This value was used to establish the limitation on unprotected openings in the BNBC, as well as those corresponding to "moderate" severity of NFiPA 80A - *Recommended Practice for Protection of Buildings from Exterior Fire Exposures.*[5] Values used for the "light" and "severe" classifications in NFiPA 80A are 89 and 357 kW/m^2, respectively.

Rearranging the above formula, it can be seen that the configuration factor, ϕ, is the ratio of the intensity of the radiation striking the target, I_r, to the intensity of the radiation being emitted from the burning building, I_e.

$$\phi = I_r/I_e \qquad \textbf{Eq. 1A}$$

If the emitter is a point source, the intensity of the radiation at the target varies inversely as the square of the distance between the source and the target. This means that if you double the distance between the two, the level of radiation is only 25% of what it was at the original closer distance.

However, the emitter is seldom a point source. Typically, it is one or more openings, each usually rectangular in shape. If the openings are relatively small in comparison to the facade, and uniformly distributed throughout the face of the building, the entire wall surface can be assumed to be the radiator, but radiating at some reduced level. Thus, the radiation received at the target, I_r, is determined in accordance with:

$$I_r = I_e \cdot \phi \cdot p/100 \qquad \textbf{Eq. 2}$$

where p = percent of openings in the facade

For a rectangular facade, the configuration factor, ϕ, is found from the following formula:

Eq. 3

$$\Phi = \frac{2}{\pi}\left[\frac{x}{\sqrt{x^2+y^2}} \arctan\left(\frac{z}{\sqrt{x^2+y^2}}\right) + \frac{z}{\sqrt{y^2+z^2}} \arctan\left(\frac{x}{\sqrt{y^2+z^2}}\right) \right]$$

where x = one-half the length of the radiating surface
z = one-half the height of the radiating surface
y = separation distance between the radiator and the target

note: arctan expressed in radians

The distance between the radiator and target, *y*, should be adjusted (increased) when the facade of the burning building has unprotected openings. This is necessary to account for flames projecting from the openings which reduces the effective distance between the two buildings. NFiPA 80A recommends that five feet be added to the required separation distance calculated, or subtracted from the actual distance between the two buildings. The BNBC assumed 6 feet in its calculated allowable percentage of openings.

In order to determine the distance required between buildings to prevent fire in one from igniting combustible cladding on the other, the allowable or tolerable level of radiation, I_t, permitted on the facade of the target or exposed building, must be determined. It is generally accepted that cellulosic materials (i.e., wood) will not ignite in the presence of a pilot flame after prolonged exposure to 12.5 kW/m^2 or less radiation. The pilot ignition value, versus the spontaneous ignition value is used since it is assumed that a spark in the form of a flying brand is likely to be present to ignite the volatile gases being liberated from the irradiated material. The tolerable level of radiation, I_t, used to develop the unprotected openings limitations in BNBC and NFiPA 80A as well as many other codes throughout the world is 12.5 kW/m^2.

Rearranging Equation 2, the allowable percentage of openings can be calculated.

$$p = 100 \cdot I_r / I_e \cdot \phi \qquad \textbf{Eq. 4}$$

However, since I_e is equal to 179 kW/m^2 and I_r equals I_t, which equals 12.5 kW/m^2, Equation 4 can be simplified to:

$$p = 100\,(12.5)/(179) \cdot \phi = 7/\phi \qquad \textbf{Eq. 5}$$

By using Equation 5, one can calculate the allowable percentage of unprotected openings for any building facade, provided the openings are uniformly distributed throughout the facade.

METHODOLOGY DEFICIENCIES IN MODEL CODES

While two adjacent buildings may have initially been built with adequate fire separation distance between them, there is always the possibility that one building may be torn down and another erected closer to the property line. Technically, under these circumstances, the new building should be required to protect itself from the adjacent building. Thus far, this approach has been considered undesirable by code writers. Adequate separation distances can be calculated as described in the previous section, but the methodology is not readily adaptable for codification.

For codification purposes, rather than being left with an infinite number of possible separation distance combinations in order to meet set-back requirements, a more practical approach is to regulate the amount of unprotected openings based on the assumption that a combustible facade (target) will be located at some assumed set back from the opposite side of the property line. This appears to have been done in the BNBC, since it requires combustible veneers to be set back a minimum of 5 feet from the property line. The methodology used, however, incorporates a technique that leads to erroneous results for some exposure scenarios.

Upon review, it is determined that the BNBC used what is commonly referred to as the "mirror image" concept to establish its opening limitations. This means that buildings on opposite sides of the property line are assumed to be identical in every respect, including set-back distance, length, height, percentage of openings, and emitted radiation, I_e. This approach assures adequate protection when the burning building is set back the minimum distance at which openings are permitted (i.e., generally 5 feet under the BNBC). However, it provides less than adequate protection when the burning building is located at greater distances from the property line. For example, if the burning building is moved back to have a 30 ft set back (the distance at which 100% unprotected openings are permitted by the code), and the exposed building with combustible cladding remains at its minimum required set back of 5 feet, the radiant energy received by cladding is 33.82 kW/m^2, or 2.7 times the allowable value of 12.5 kW/m^2. Whereas, using the mirror image concept, the analysis of a building with a 30 ft set back places both buildings 30 feet from the property line, resulting in a separation distance of 60 feet instead of 35 feet. If one subtracts 6 feet to account for the plume position, the actual distance from the radiator to the target that is reflected in the analysis is 54 feet, and the corresponding radiant energy striking the exposed building is now an acceptable 12.5 kW/m^2.

The above illustrates the fallacy of utilizing the mirror image approach to establish opening limitations. It provides adequate protection in a few cases, but not in all cases. The greater distance the burning building is set back (but not greater than 30 feet) with the code-allowed percentage of openings, the greater hazard it presents to a neighboring building with minimum set-back distance (i.e., 5 feet) and combustible cladding.

One other scenario under the BNBC that yields non-conservative results is when a burning building with 10% unprotected openings, per Table 905.3, is set back 5 feet and the exposed (target) building also has a five ft set back. Although this is one of the few cases where the mirror image concept should work (based on a 15' x 49' radiator used to establish the BNBC opening limitations), calculations show that the intensity of radiation striking the target (I_r) under these conditions is 15.7 kW/m^2. This exceeds the tolerable level of 12.5 kW/m^2, and occurs because the values in Table 905.3 have been rounded to the nearest 5%. The actual percentage of openings that is necessary to limit the radiation emission from exceeding the tolerable level is 7.96%.

In the SBC, although the methodology used in determining opening protection and set-back distances appears to have been based on fire protection engineering principles for certain scenarios, this does not hold true for all cases. As for the *Uniform Building Code* [6] (UBC), there is no readily apparent scientific basis for the determination of its opening limitation and set-back distance requirements.

CORRECTING THE DEFICIENCIES WITH A CODIFIED APPROACH

Table 1 provides one possible solution for correcting the deficiencies previously described. The table values are derived from the configuration factor relationship in Eq. 3, and are consistent with the physics used in establishing the set-back and opening protection provisions contained in the BNBC. The following example combines a scientific methodology and a codified approach for the problem at hand.

Example

Given: Exposing building 15' high by 60' wide; building separation between buildings = 20'; distance between radiator and target = 20' - 6' = 14'.

Determine the percentage of allowable openings in the exposing building.

From the table,
ratio of width to height = W/H = 60/15 = 4.

Using the formula; guide number x lesser bldg. dimension = distance between radiator and target,

guide number = 14/15 = 0.933

Going into the table using the above guide number and W/H ratio, indicates that the maximum percentage of unprotected openings that is allowed is approximately 15%. Through interpolation, the actual maximum is 15.5%. Therefore, for buildings of similar dimension that are located 20' apart, the allowable percentage of openings should not exceed 15%.

Alternatively, if greater openings are desired, the table can be used to determine the minimum separation distance that is needed for a given percentage of openings.

Given: 40% unprotected openings for the same exposing building.

Determine the minimum separation distance needed.

From the table, using 40% openings and the
W/H ratio = 4, yields a guide number = 2.18

Table 1. Determination of Separation Distances and Percentage of Openings

Width/Height or Height/Width	1.0	1.3	1.6	2.0	2.5	3.2	4	5	6	8	10	13	16	20	25	32	40
Percent Openings*	Guide Number (multiply by lesser dimension to get distance between radiator and target)																
10	0.36	0.40	0.44	0.46	0.48	0.49	0.50	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
15	0.60	0.66	0.73	0.79	0.84	0.88	0.90	0.92	0.93	0.94	0.94	0.95	0.95	0.95	0.95	0.95	0.95
20	0.76	0.85	0.94	1.02	1.10	1.17	1.23	1.27	1.30	1.32	1.33	1.33	1.34	1.34	1.34	1.34	1.34
25	0.90	1.00	1.11	1.22	1.33	1.42	1.51	1.58	1.63	1.66	1.69	1.70	1.71	1.71	1.71	1.71	1.71
30	1.02	1.14	1.26	1.39	1.52	1.64	1.76	1.85	1.93	1.99	2.03	2.05	2.07	2.08	2.08	2.08	2.08
40	1.22	1.37	1.52	1.68	1.85	2.02	2.18	2.34	2.48	2.59	2.67	2.73	2.77	2.79	2.80	2.81	2.81
50	1.39	1.56	1.74	1.93	2.13	2.34	2.55	2.76	2.95	3.12	3.26	3.36	3.43	3.48	3.51	3.52	3.53
60	1.55	1.73	1.94	2.15	2.38	2.63	2.88	3.13	3.37	3.60	3.79	3.95	4.07	4.15	4.20	4.22	4.24
80	1.82	2.04	2.28	2.54	2.82	3.12	3.44	3.77	4.11	4.43	4.74	5.01	5.24	5.41	5.52	5.60	5.64
100	2.05	2.30	2.57	2.87	3.20	3.55	3.93	4.33	4.74	5.16	5.56	5.95	6.29	6.56	6.77	6.92	7.01
---	2.26	2.54	2.84	3.17	3.54	3.93	4.36	4.82	5.30	5.80	6.30	6.78	7.23	7.63	7.94	8.18	8.34
---	2.63	2.95	3.31	3.70	4.13	4.61	5.12	5.68	6.28	6.91	7.57	8.24	8.89	9.51	10.05	10.50	10.84
---	2.96	3.32	3.72	4.16	4.65	5.19	5.78	6.43	7.13	7.88	8.67	9.50	10.33	11.15	11.91	12.59	13.15

*Assumes equally distributed windows.

Values apply only for emitter of moderate severity (i.e., I_e = 17.9 kW/m^2)

Source: Adapted from NFPA 80A

Using the formula; guide number x lesser bldg. dimension = distance between radiator and target,

2.18 x 15 = 32.7 ft between the radiator and target.

Adding 6 ft to account for the flame dimension, means that the buildings must be separated by a distance of no less than 38.7 ft, if 40% unprotected openings are used.

Fire Ratings Of Exterior Walls

If openings must be limited to prevent radiation in excess of that necessary to cause pilot ignition of combustible veneers, it is equally important that the opaque portions of exterior walls be fire resistance rated. Requiring walls to be fire resistance rated assures that they will withstand the standard E119 fire test exposure for the specified time period. This will not only provide for the structural integrity of the wall, but will also assure that the wall will not get hot enough to contribute significantly to the radiant heat energy being emitted through the openings.

The wall should have a rating sufficient to assure that it will be able to withstand the complete burnout of the combustible contents anticipated to be in the building. This will vary depending on the use of the building, and can range from a few pounds per square foot, to 100 or more pounds per square foot. Table 905.2 of the BNBC for walls with a fire separation distance of 5 feet or less is based on this premise. The minimum fire resistance ratings recommended for exterior walls, based on the building occupancy or use, are shown in Table 2.

Table 2. Minimum Recommended Fire Resistance of Exterior Walls

Building Use or Occupancy	Fire Resistance Rating
Assembly, Business, Educational, Institutional, Residential (Except Single-Family), and Low Hazard Factory or Storage	2
Residential (Single-Family Only)	1
Moderate Hazard Factory or Storage, and Mercantile	3
High Hazard	4

Note a: Rating of load bearing walls shall not be less than that required based on building type of construction.

When Are Rated Exterior Walls Required?

After determining what the rating of an exterior wall should be, one must determine at what distance from the property line an exterior wall needs to be fire resistance rated. The answer is simple. If openings must be limited to prevent ignition of combustible cladding, the opaque wall must be fire resistance rated. In other words, non-rated walls should be permitted only when the percentage of unprotected openings is not limited.

If opening limitations and wall ratings are not coordinated, limiting openings may be useless. If the burning building has non-rated walls, they may be compromised (burnt through), thus creating a larger percentage of openings than is permitted. For example, Table 600 of the SBC limits unprotected openings in an exterior wall to 20% in Type IV unprotected construction with 10 to 20 feet fire separation distance. However, the same table also permits exterior walls with greater than 10 feet fire separation distance to be non-rated. Therefore, when the wall burns through, it will have 100% unprotected openings instead of the 20% envisioned by the code. If the adjacent building has an exterior wall with a combustible veneer, the incident radiant energy striking the cladding will be 5 times that contemplated by the code. The likely result would be the ignition of the cladding.

Limitation on the Use of Combustible Veneers

As previously indicated, the best approach for code writers is to regulate how close a combustible veneer can be located with respect to the property line. Regardless of the required set back, there are certain ramifications that should be considered. If the set back is sufficiently large, say greater than 40 feet, the possibility exists that radiant energy may ignite combustibles within the exposed building since the radiation will be transmitted through protected or unprotected openings. On the other hand, if combustible veneers are permitted at relatively close set backs, say less than 5 feet, there is the possibility of ignition due to direct flame impingement from a burning building on the opposite side of the property line.

It has already been mentioned that the BNBC requires combustible veneers to be set back a minimum of 5 feet. The SBC and UBC require wood veneers on buildings with noncombustible exterior walls to be set back 30 and 40 feet, respectively. In addition, these codes limit the height of wood veneers to 2 stories or 15 feet, respectively, unless fire retardant treated wood (FRTW) is used, in which case the height can be increased to 4 stories or 35 feet. Other combustibles, such as light transmitting plastic wall panels, plastic glazing, and plastic veneers are restricted by codes with respect to set backs from property lines, maximum panel sizes, panel separation requirements, and height limitations. However, there are still some combustible veneers for which adequate regulation is lacking. One such example is the use of exterior insulation and finish systems (EIFS). Currently, none of the three model codes limit the application height of EIFS, or have minimum set-back requirements pertaining to them. Stricter code provisions are needed for buildings with combustible cladding, if the spread of fire from building to building is to be adequately controlled.

Radiant heat from the burning building melted the vinyl siding of two buildings 80 feet away. The damage shown provides evidence that the level of heat exposure was below that which would cause the pilot ignition of wood.

Additional data needs to be obtained about the ignition and burning characteristics of combustible cladding materials through standardized testing. Until combustible cladding can be shown to resist equal or greater levels of radiant energy than wood, all combustible cladding should be regulated identically as wood veneers.

RECOMMENDATIONS

Based on the foregoing, the recommendations listed below should be followed in developing code provisions that properly address the prevention of fire spread from building to building via the exterior wall.

1 Require that unprotected openings in buildings be limited so that the amount of radiant energy is maintained at or below the code-established value, at a code-specified distance from the property line. For example, the code may require that unprotected openings be limited so that radiation at 5 feet from the opposite side of the property line does not exceed 12.5 kW/m^2.

2 Require that exterior walls have a fire resistance rating when unprotected openings are limited, based on Item 1 above. The rating should be in accordance with Table 2.

3 Establish a minimum base-line set back for the installation of combustible veneers of all types, including EIFS, plastic veneer, and light transmitting plastic wall panels or glazing. This base-line set-back distance should be the same for all combustible materials, and coordinated with Item 1 above.

4 Require that combustible veneers other than wood be subjected to a radiant panel test to determine the maximum amount of radiant energy that they can withstand without igniting in the presence of a pilot flame.

5 Until the ignition properties of combustible cladding can be compared with those of wood through the use of standardized tests, require all combustible cladding to be regulated the same as wood veneers.

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