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Designing Fire Protection for Steel Trusses

Subcommittee on Fire Technology of the Committee on Construction Codes and Standards

American Iron and Steel Institute

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DESIGNING FIRE PROTECTION FOR STEEL TRUSSES

INTRODUCTION

In many occupancies, modern structural steel systems often employ trusses as a means of achieving a high degree of spatial flexibility. For many truss applications, building codes require structural fire-resistance ratings of two or three hours based on *Standard Methods of Fire Tests of Building Construction and Materials,* ASTM E119 (NFPA 251, UL 263). This presents a problem for trusses since Standard Fire Test furnaces are incapable of testing constructions incorporating large elements. Thus, with the size of test specimens effectively limited and in the absence of specific criteria in test methods to establish fire ratings for trusses, concepts are proposed here for determining fire-protective designs by applying existing test data from ASTM E119 fire tests. These methods have been accepted by many code authorities and are discussed later in this publication.

While fire protection for all building trusses is broadly discussed, specific procedures are given for staggered and interstitial truss designs as well as for trusses individually protected with spray-applied materials. Emphasis must be made of the fact that these are rational engineering methods for complying with fire code fire-resistance requirements for steel trusses. They apply existing authoritative fire-test data derived from hundreds of standard fire tests to the design of truss fire protection.

In this publication reference is made to specific requirements in three model building codes that are widely used in the United States. Their full names and respective sponsoring organizations are:

> *Basic Building Code,* 8th Edition (1981), Building Officials and Code Administrators International (BOCA), 17926 South Halsted Street, Homewood, Illinois 60430.
>
> *Standard Building Code,* 1979 Edition, Southern Building Code Congress International (SBCCI), 900 Montclair Road, Birmingham, Alabama 35213.
>
> *Uniform Building Code,* 1979 Edition, International Conference of Building Officials (ICBO), 5360 South Workman Mill Road, Whittier, California 90601.

In most cases, communities that regulate building construction do one of two things: they either directly adopt one of these codes or enforce a set of regulations patterned after one of them. As a result, provisions in the three model codes are generally considered to be typical of United States practice despite the fact that some states and jurisdictions maintain locally developed building codes. It should be noted that even those communities that utilize one of the model codes sometimes enact amendments for their own localities. *As a result, all the provisions in the applicable building code should be carefully investigated before designing a fire-protection system for steel trusses.*

BUILDING CODE REQUIREMENTS

For all practical purposes, there are three basic fire-protection techniques for steel trusses:

1) Fire-resistant ceiling systems,
2) Individual protection for each truss element or member—usually with a spray-applied material, or
3) Enclosing the truss assembly for its entire height and length with fire-resistant materials.

Relative to fire-resistance requirements, many building codes distinguish between trusses according to their particular structural function. These distinctions should be carefully noted and studied since they affect both 1) the level of fire protection required, and 2) the permissible methods of protection.

As to the level of required fire protection, both the Standard and Basic Building Codes differentiate between trusses that support roof construction, those that support only one floor, and trusses that support more than one floor. These differences appear in the tabulated fire-resistance requirements as a function of "Construction Type" (Table 401 in the *Basic Building Code* and Table 600 in the *Standard Building Code*). Generally speaking, the *Uniform Building Code* does not make a similar distinction in that the "structural frame" is treated as a total entity.

Additionally, for roof trusses, *Basic Building Code* fire-resistance requirements vary according to the height of the truss above the floor level. Similar provisions in the *Uniform* and *Standard Building Codes* apply to *assembly* and *educational* occupancies.

As to the permitted methods of truss protection, the 1981 *Basic Building Code* states:

> *1411.2 Protection of structural members:* Columns, girders, trusses, beams, lintels, or other structural members that are required to have a fire resistance rating and that support more than two floors or one floor and roof, or support a bearing wall or a non-bearing wall more than two stories high, shall be individually protected on all sides for their length or height with materials having the required fire resistance rating. All other structural members required to have a fire resistance rating may be protected by individual encasement, by a membrane or ceiling protection as specified in Section 1412.0, or by a combination of both.

Current provisions relative to protection methods in the *Uniform Building Code* (Section 4303) are quite similar to the BOCA Code except that fire-resistant ceiling membranes cannot be used to protect trusses that support loads from more than one floor or roof. The *Standard Building Code* makes no distinction between the number of floors supported and the method of fire protection permitted. Since a clear distinction is made between trusses according to their structural function, building code fire protection provisions translate into somewhat different requirements for three common truss applications: *transfer trusses, staggered trusses,* and *interstitial trusses.*

In addition to general fire-safety provisions, all three model building codes (BOCA, SBCCI and ICBO) contain comprehensive requirements for high-rise buildings (i.e., those with floors located *over 75 ft above the lowest level* of fire department vehicle access). Generally, these high-rise provisions contain two options: compartmentation or automatic sprinkler protection. The sprinkler option, in BOCA and SBCCI, permits a reduction in the required structural fire resistance—a fact that deserves careful consideration.

Transfer Trusses

The most frequent use of load transfer trusses is to create a clear space on a lower floor by directly supporting the loads from columns above the truss—or, at times, from tension members below. This technique makes is possible to design large, column-free areas for auditoriums, ballrooms, and the like. Figure 1 illustrates an interesting example of Vierendeel load-transfer trusses on the sixteenth floor of a seventeen-story structure, thereby permitting the omission of central columns

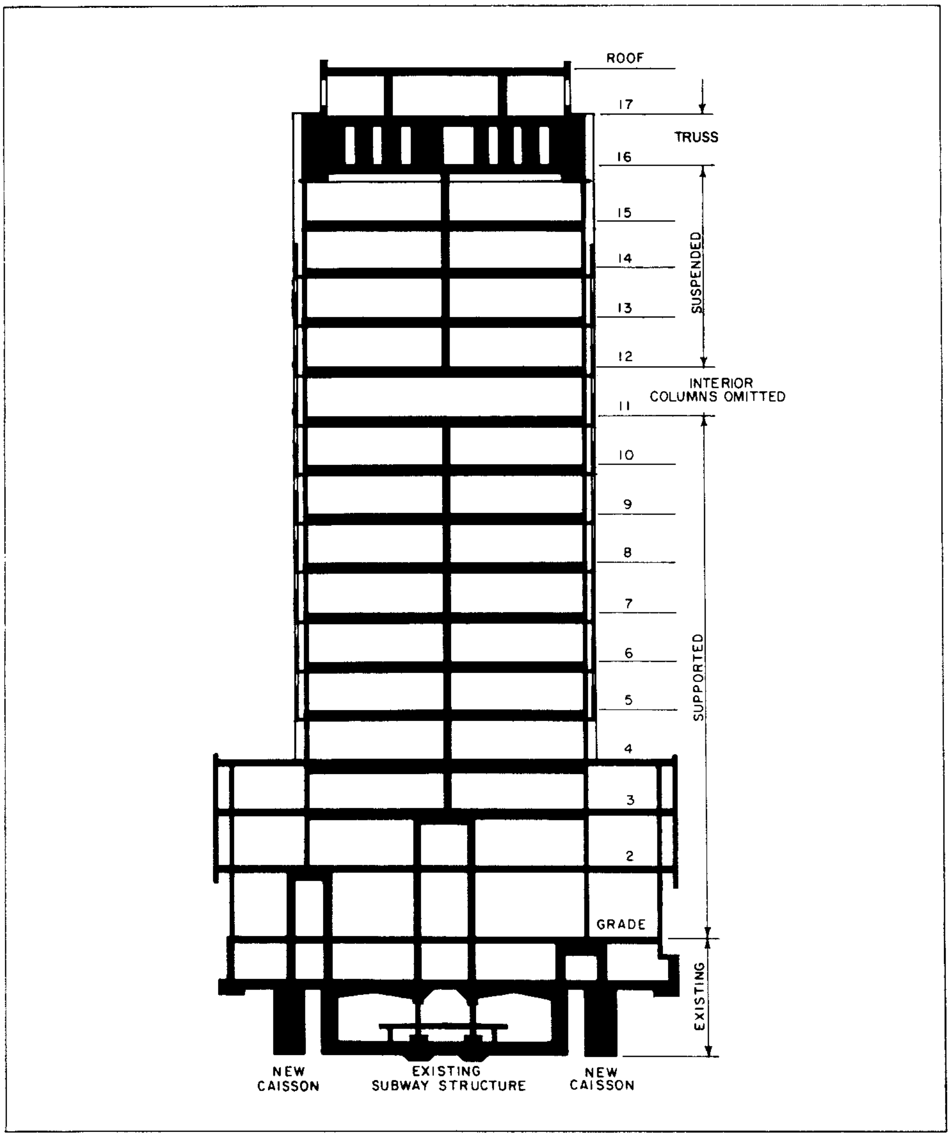


Figure 1. Vierendeel truss providing support from above and below.

on the eleventh floor. In this instance, tension members extend for four stories and support the twelfth through fifteenth floors.

Recently, a similar concept was employed in the twenty-three-story addition to the Chicago Board of Trade building. Here, eight two-story deep, load transfer trusses were used to create a 26,000 sq ft column-free area for the main trading floor.

Since transfer trusses carry load from more than two floors, building codes generally require that the fire protection be provided by individual protection for each of the truss elements, or by complete enclosure of the truss (for its entire height and length) with envelope protection.

Staggered Trusses

The staggered truss system (Fig. 2), developed by the Departments of Architecture and Civil Engineering of the Massachusetts Institute of Technology, is a unique structural concept. It is primarily intended for high-rise residential buildings, either apartment houses or hotel/motel structures. Typically, in a staggered truss design, story-high trusses span the full building width at alternate column lines on each floor. These trusses are supported, only at their ends, on the two rows of exterior columns. Thus, the interior of the building is column-free. At any given elevation, floor construction is alternately supported on the top and bottom chords of adjacent trusses.

It is characteristic of staggered truss applications that these trusses are enclosed in wall construction that separates individual apartments or hotel/motel guest rooms. Ordinarily, there is a central opening in the truss that permits passage space for a corridor. Where architectural layouts make it necessary, provisions for additional openings can be made. Fire-protective design for a staggered truss system demands investigation of a number of building code provisions. Because quite a few truss arrangements are possible, a wide variety of layouts can be created.

Most building codes require a one-hour fire-resistance rating for walls or partitions that separate individual apartments or hotel/motel guest rooms. Since, in these occupancies, staggered trusses are usually enclosed in walls, the entire wall assembly must therefore have a fire resistance of one hour. Additionally, since the trusses support loads from two floors, consideration should be given to two factors: 1) the level of required fire resistance, and 2) the permissible fire-protection methods. As mentioned earlier, both the Basic and Standard Building Codes require a higher level of fire resistance for trusses that support loads from more than one floor.

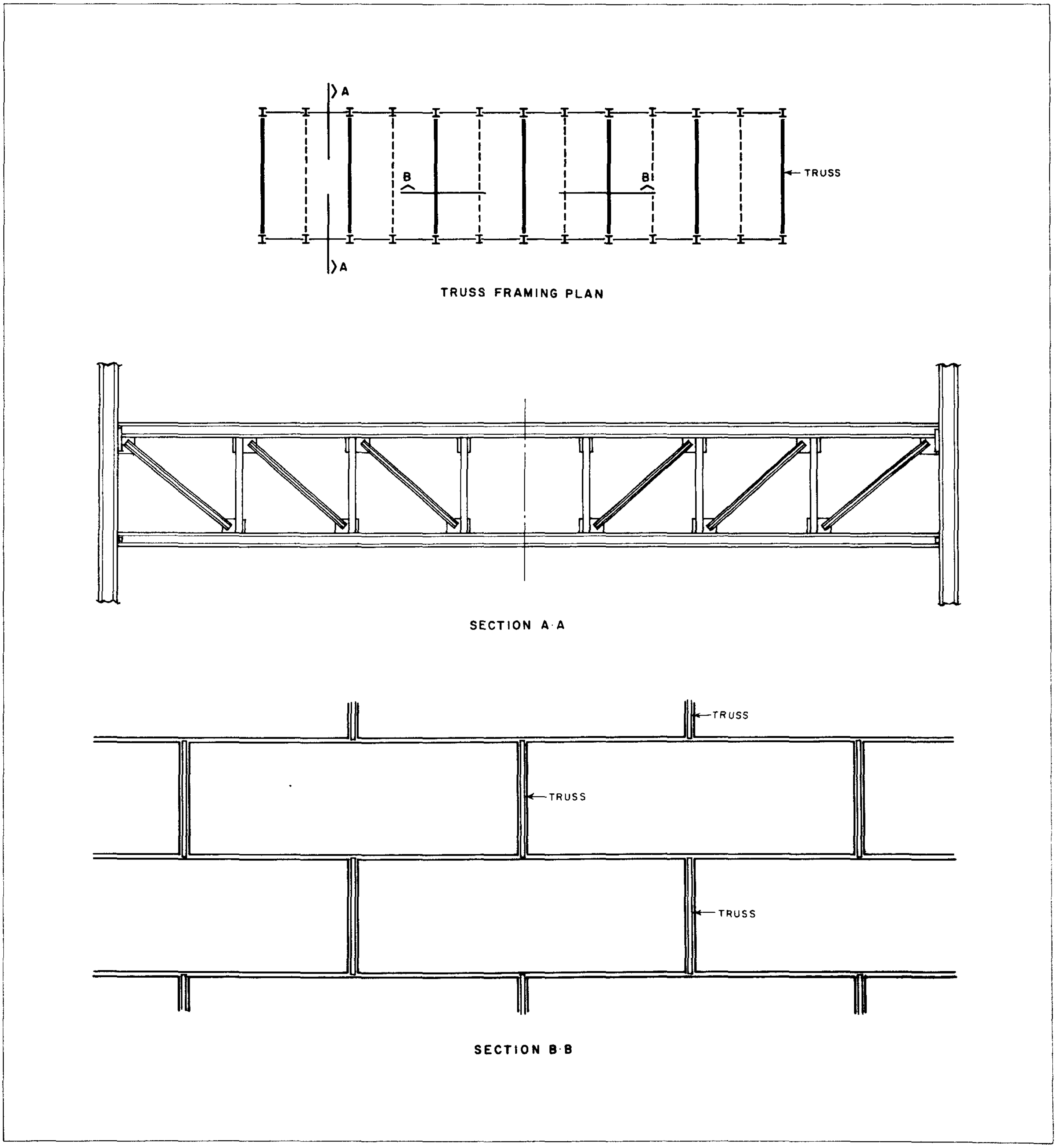


Figure 2. A typical truss and positionings in a *staggered truss system.*

Uniform Building Code provisions apply to the total structural frame and generally make no distinction as to the number of floors supported by the individual structural members.

Because of the layout or spatial configuration characteristic of staggered-truss building design, the most practical and proven method of achieving the required fire resistance is to enclose the truss for its entire height and length with envelope protection. Previously, there were specific requirements in many building codes for individual protection of each truss element if the truss supported loads from more than one floor. At present, however, recent changes in all three major model building codes permit envelope protection for staggered-truss applications. The pertinent provisions are set forth in Section 4303(b) 8 of the *Uniform Building Code,* 1411.2 of the *Basic Building Code,* and Appendix B to the *Standard Building Code.*

Among the growing number of buildings that utilize the staggered-truss structural system are: The Briarcliff Apartments, Cliffside Park, New Jersey; Hyatt Regency Hotel, Columbus, Ohio and Lexington, Kentucky; Holiday Inn, Bloomington, Minnesota; Radisson Hotel, Lexington, Kentucky.

Interstitial Trusses

As was the case with the staggered-truss structural system, the interstitial truss concept was developed primarily to solve the functional needs of a specific occupancy type. In this instance, (Fig. 3), the problem involved hospital construction.

While steel trusses in interstitial framing systems are quite deep (on the order of 8 ft in height), they do not extend from floor-to-floor as do staggered trusses. The top chords support the floor above, while the bottom chords support a suspended ceiling system and a walk-on surface for maintenance purposes. As such, interstitial trusses are analogous to very deep open-web steel joists.

The interstitial space thus created, provides a convenient location for the complex mechanical and electrical systems that are necessary components of a modern hospital structure. Added to this is the advantage of having direct access, for maintenance, renovation and replacement of the various system components within these inter-floor spaces without significant interference with normal hospital operations.

Since each interstitial truss supports only one floor, all three conventional fire-protection methods for trusses are permitted by the model building codes. However, because of practical considerations, individual protection of each truss element or ceiling membrane protection are the most widely used in interstitial construction.

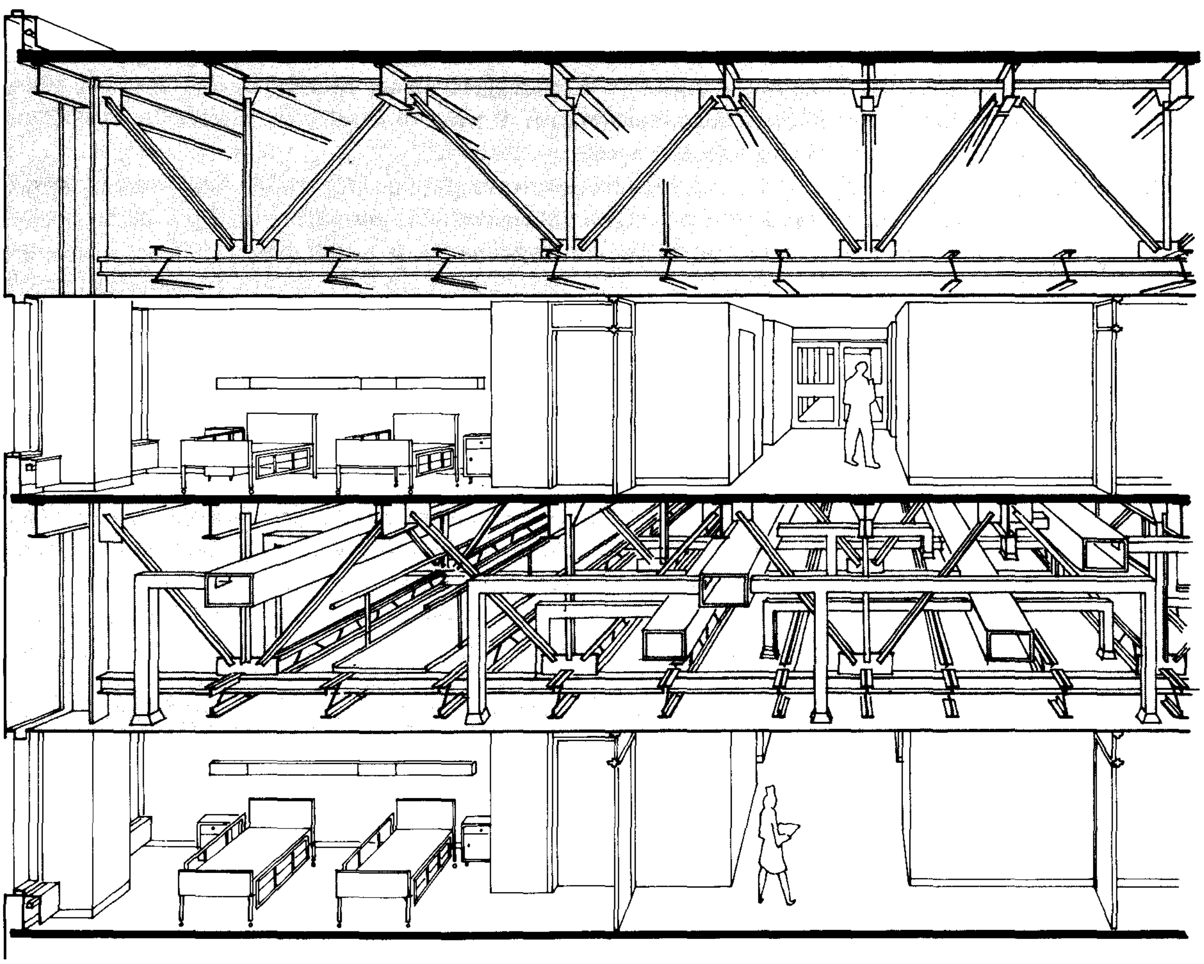


Figure 3. Section through hospital floors and walk-through ceiling spaces created by the *interstitial truss system*.

DESIGN CONCEPTS

As noted, steel trusses can, in a unique manner, provide efficient solutions to a number of common structural problems. When used in certain applications, building codes require truss protection that will develop specified levels of fire resistance. Because of their relatively large size, it is—in most cases—impractical to conduct standard fire tests on truss assemblies under conditions truly representative of actual installed conditions. While a single ASTM E119 fire test has been conducted on a staggered-truss assembly and at least two tests on interstitial truss assemblies, it was not feasible to structurally load the trusses during any of the tests.

Recognizing the testing limitations imposed by large steel trusses, building codes have recently adopted revisions permitting truss fire protection to be designed on the basis of judicious use of test data derived from similar assemblies. For example, the *Uniform Building Code* (ICBO) now contains the following provision:

> *4303(b) 8 Truss Protection.* Where trusses are used as all or part of the structural frame and protection is required by Table No. 17-A, such protection may be provided by fire-resistive materials enclosing the entire truss assembly on all sides for its entire length and height. The required thickness and construction of fire-resistive assemblies enclosing trusses shall be based upon the results of full-scale tests or combinations of tests on truss components or upon approved calculations based on such tests which satisfactorily demonstrate that the assembly has the required fire resistance.

Individual Member Protection

Of the three common methods for providing the requisite fire protection for steel trusses, one involves individual protection of all truss elements considering each as a column. When employing this technique, the necessary protective thickness for any given element is determined on the basis of standard fire tests conducted on steel columns. The rationale for this concept is:

1) During the past two decades, virtually all steel column fire tests in the United States have been conducted in accordance with the "Alternative Test of Protection for Structural Steel Columns" specified in ASTM E119. This procedure provides for the testing of unloaded steel columns protected with materials that do not contribute to the load-carrying capacity of the column. The acceptance criteria specify a limiting average steel temperature of 1000°F (538°C)–1200°F (649°C) maximum at any single point.

   These temperature limits have generally been accepted as being applicable to individual elements in steel trusses. Confirmation of this can be found in the fire-resistance requirements for open-web steel joists, whose form clearly makes them "mini-trusses." For *unrestrained* classifications, ASTM E119 currently specifies a limiting average temperature of 1100°F (593°C) with 1300°F (704°C) maximum temperature at any single location for open-web steel joists.

2) When a large truss is exposed to fire, the most severe condition will generally occur when the bottom chord and diagonal elements are totally engulfed in flames. During ASTM E119 tests on column assemblies, the column is simultaneously exposed to fire on all sides. It follows, therefore, that exposure conditions for the most critical truss elements are essentially the same as the test exposure for steel columns.

As a result, building code and fire protection authorities will usually accept truss fire-protection design based on steel column test data. Both the Uniform and Standard Building Codes give specific recognition to this concept. However, two practical problems exist in the direct application of column test results to common truss configurations. First, virtually all existing column tests have been conducted on wide-flange shapes whereas many truss elements are fabricated from other shapes such as structural T's, channels, and angles. Second, most column tests have been conducted on W10x49 and larger shapes while many truss elements are fabricated from smaller shapes. These two problems have, however, been resolved for a number of common fire-protection materials for steel columns as discussed in a related AISI publication, *Designing Fire Protection for Steel Columns,* 3rd Edition, 1980. On the basis of procedures described therein, the fire resistance (time to 1000°F limiting temperature) of individual truss elements protected with spray-applied cementitious or mineral fiber fire-protection materials can be determined from the following general equation:

$$R = \left[C_1 \left(\frac{W}{D}\right) + C_2\right] h$$

Where R = fire resistance (minutes),
h = thickness of spray-applied protection (inches),
D = heated perimeter of the truss element (inches),
W = weight of the truss element (lb/ft), and
C_1 and C_2 = material-dependent constants determined for specific fire protection materials on the basis of ASTM E119 Standard Fire Tests. (Each spray-applied material has its own set of constants.)

For the cementitious material identified in UL Design Nos. X701, X704, X722 and X723, the material-dependent constants are $C_1 = 69$ and $C_2 = 31$ and the resulting equation is:

$$R = \left[69 \left(\frac{W}{D}\right) + 31\right] h = \text{minutes}$$

For the mineral fiber material identified in UL Design Nos. X801, X807, X818, X821, and X822, the material-dependent constants are $C_1 = 63$ and $C_2 = 42$ and the resulting equation is:

$$R = \left[63 \left(\frac{W}{D}\right) + 42\right] h = \text{minutes}$$

The *heated perimeter* (D) is defined as the inside perimeter of the applied fire-protection material. Figure 4 illustrates procedures for determining the value of D for a number of common truss elements.

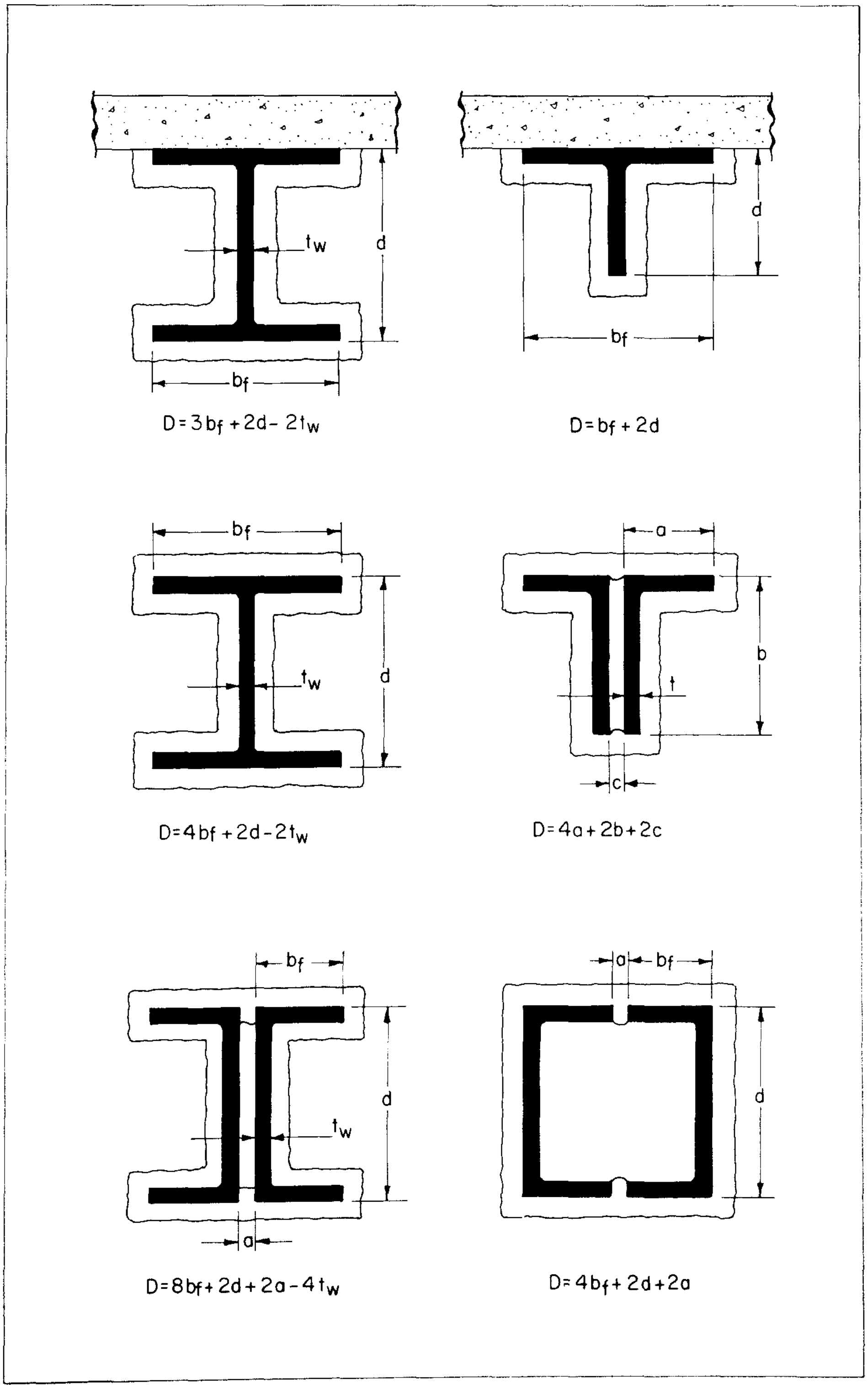


Figure 4. The D factor represents the shape—or heated perimeter—of the fire-protection system. For typical truss elements, this factor is derived by using the formula given for each of the cases shown.

Staggered Truss Systems

As previously noted, in most applications the staggered trusses are enclosed in walls or partitions that separate individual apartments or hotel/motel guest rooms. As a result, the entire wall assembly must satisfy applicable building code requirements for walls and partitions in addition to the structural fire-resistance requirements for the truss. This can be met by using a combination of spray-on fire proofing and gypsum wallboard enclosure of the truss (see UL Design U805).

Fire protection for current staggered-truss projects has been achieved with the use of gypsum wallboard/light-gage steel stud systems similar to that illustrated in Figure 5. In most cases, this technique has proven more economical than the combined use of spray-applied materials and gypsum wallboard.

The design shown (Fig. 5) is based upon an analysis of numerous standard fire tests on light-gage steel stud/gypsum wallboard assemblies. Note that this design includes two alternatives with respect to the specified types of gypsum wallboard. The first alternative involves single or multiple layers of any UL classified ⅝-inch thick Type X gypsum wallboard. The second involves triple layers of ½-inch thick Type C gypsum wallboard. Type C wallboard has improved fire-resistance characteristics as compared to the conventional Type X.

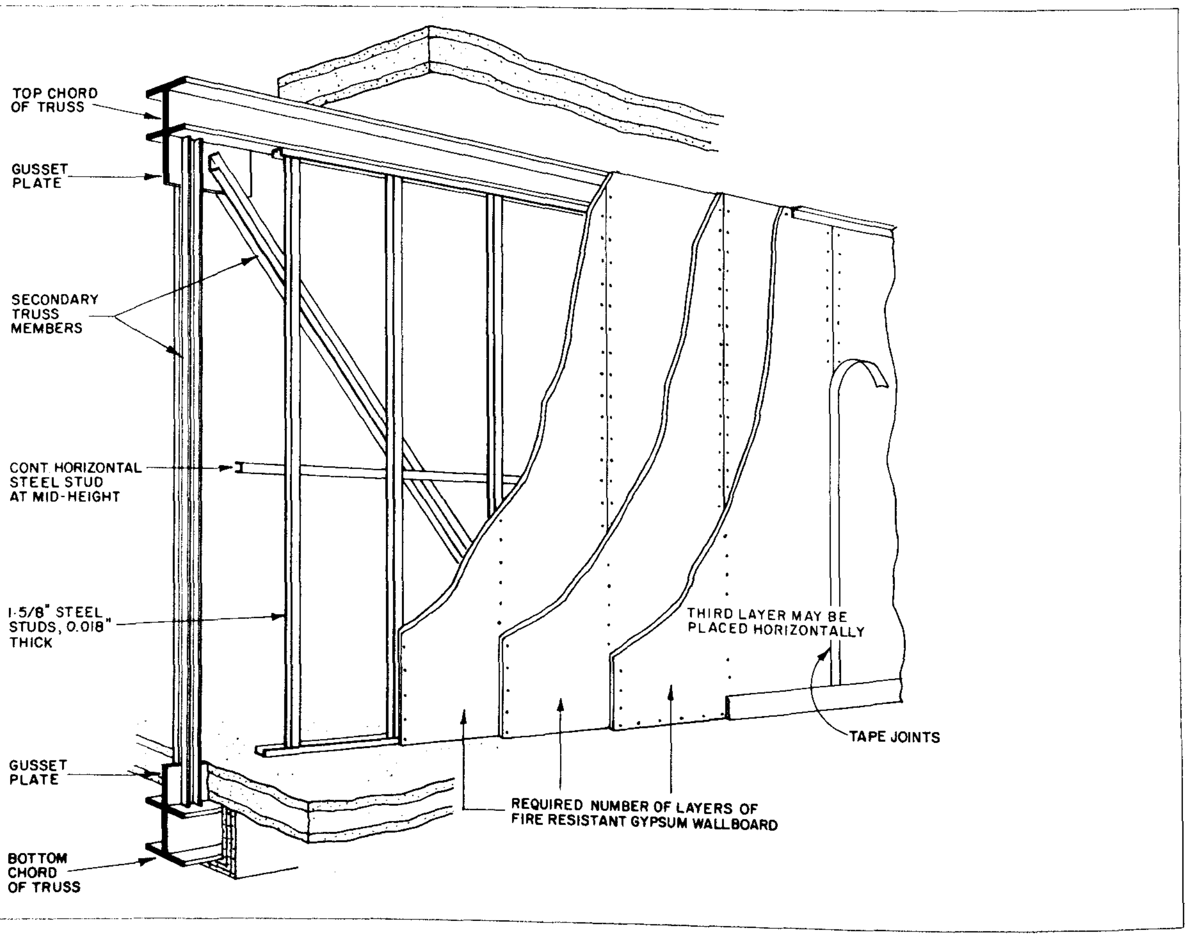


Figure 5. Cutaway drawing showing a staggered truss protected with gypsum wallboard on steel studs.

SUGGESTED CONSTRUCTION DETAILS FOR FIRE PROTECTION OF STAGGERED TRUSSES

Steel Studs:

Studs, either 1⅝, 2½, or 3⅝ inches deep, fabricated from 0.0179 inch minimum thickness corrosion-protected steel. The length of the steel studs shall be at least ¼-inch less than the overall height of the assembly.

Floor and Ceiling Tracks:

Steel studs shall be installed in channel shaped floor and ceiling tracks fabricated from 0.0179-inch minimum thickness corrosion-protected steel. The track width shall be compatible with the depth of the steel stud. The track legs shall be at least 1-inch deep. Tracks shall be attached to the floor and ceiling with fasteners spaced 24 inches O.C.

Bracing:

The steel studs shall be cross braced at the third points using either of two types of braces. Type 1 shall consist of a section of the floor and ceiling tracks cut to the appropriate length and fastened to the stud webs with two ½-inch long No. 8 self-drilling, self-tapping steel screws at each end. Type 2 shall consist of 12-inch wide sections of gypsum wallboard cut to the appropriate length and fastened to the stud webs with three 1-inch long Type S wallboard screws at each end.

Thermal or Acoustical Insulation:

(Optional) Glass fiber or mineral wool insulation in either batt or blanket form may be installed between the steel studs for thermal or acoustical purposes.

Gypsum Wallboard:

Any ⅝-inch thick Type X gypsum wallboard with beveled, square or tapered edges (ASTM C36) or ½-inch thick Type C gypsum wallboard (US Gypsum Co.) as follows:

1 Hour Wall Assembly Rating, and
1 Hour Truss Rating

One layer of ⅝-inch thick Type X gypsum wallboard applied vertically with joints centered over steel studs. The wallboard shall be fastened to the steel studs with 1-inch long Type S screws spaced 8 inches on center at the joints (⅜ inches from the board edges) and 12 inches on center in the field. The screws shall be spaced 8 inches on center along the floor and ceiling tracks.

2 Hour Wall Assembly Rating, and
2 Hour Truss Rating

Two layers of ⅝-inch thick Type X gypsum wallboard with the first layer applied as specified for 1-hour ratings. The second layer shall be applied vertically with the joints staggered 24 inches from the joints in the first layer. The wallboard shall be fastened to the steel studs (through the first layer) with 1⅝-inch long Type S screws spaced 8 inches on center at the joints (⅜ inches from the board edges) and 12 inches on center in the field. The screws shall be spaced 8 inches on center along the floor and ceiling tracks.

2 Hour Wall Assembly Rating, and
3 Hour Truss Rating

Three layers of ½-inch thick Type C gypsum wallboard with the first two layers applied as specified for 1- and 2-hour ratings. The third layer may be applied horizontally. The wallboard shall be fastened to the steel studs (through the first two layers) with 2½-inch long Type S screws spaced 8 inches on center at the joints (⅜ inches from the board edges) and 12 inches on center in the field. The screws shall be spaced 8 inches on center along the floor and ceiling tracks.

Joint Tape and Compound:

Vinyl or casein, dry or premixed joint compound shall be applied in two coats over all joints and screw heads on the outer layer of wallboard. Paper tape, 2-inches wide, shall be embedded in the first layer of compound over all joints.

Interstitial Truss Sytems

Since interstitial trusses only support loads from one floor, any of the three aforementioned methods of obtaining the requisite fire resistance is permissible. However, in actual practice, all interstitial buildings are designed either with individual spray-applied protection for the trusses or ceiling membrane protection.

Spray-applied fire protection should be designed to comply with the principles set forth in the discussion titled *Individual Member Protection.* Ceiling protection system designs are based directly upon tested assemblies incorporating fire-resistant ceilings suspended from otherwise unprotected open-web steel joist floor assemblies.

For interstitial trusses, the rationale for basing ceiling membrane protection designs on tests of open-web steel joist assemblies is derived from two widely accepted principles:

1) Individual web and chord members in a steel joist weigh considerably less than corresponding elements in an interstitial truss. Further, it is well established that the heavier the steel shape, the longer it takes to reach a given critical temperature when exposed to fire. (For this reason the UL Fire Resistance Directory permits direct substitution of larger steel joists than those tested.)

   It is apparent, therefore, that using test results from assemblies involving steel joists, is a conservative procedure for interstitial trusses. However, this approach is subject to one qualification: Since substituting interstitial trusses for steel joists is based upon the time that it takes to reach critical temperatures, only "unrestrained" assemblies should be used as a basis for design. (Note that "unrestrained" ratings are based on the time when limiting temperatures are reached, while "restrained" ratings are usually based on the time that structural failure occurs.)
2) Interstitial space between the suspended ceiling and the floor slab above has, of course, considerably greater volume than the concealed space in a typical steel joist/suspended ceiling system. This is yet another factor that tends to increase the fire resistance of an interstitial truss assembly above that which is obtained from a steel joist test. Again, the UL Fire Resistance Directory confirms this logic by permitting both the lowering of a suspended ceiling system and the use of intermediate supports provided that they have a stiffness equivalent to that of the original test assembly. (Note that the UL Directory contains specific recommendations for designing intermediate supports.)

Consequently, fire-resistant designs for interstitial truss systems based upon tested assemblies with open-web steel joists/suspended ceilings will be conservative and are permitted through judicious use of the guidelines in the UL Fire Resistance Directory. All other details of the design—such as the protection of ceiling openings and light fixtures, as well as the design of the suspended ceiling system—must be in strict accordance with the description of the tested assembly.

One interesting application of this concept was recently used in several interstitial hospital structures (Fig. 6). Jointly developed by Armstrong World Industries and H. H. Robertson Company, this design includes a cellular steel deck system supported on crossbeams that span between the interstitial trusses. By providing a convenient "walk-on" surface for maintenance personnel, the cellular

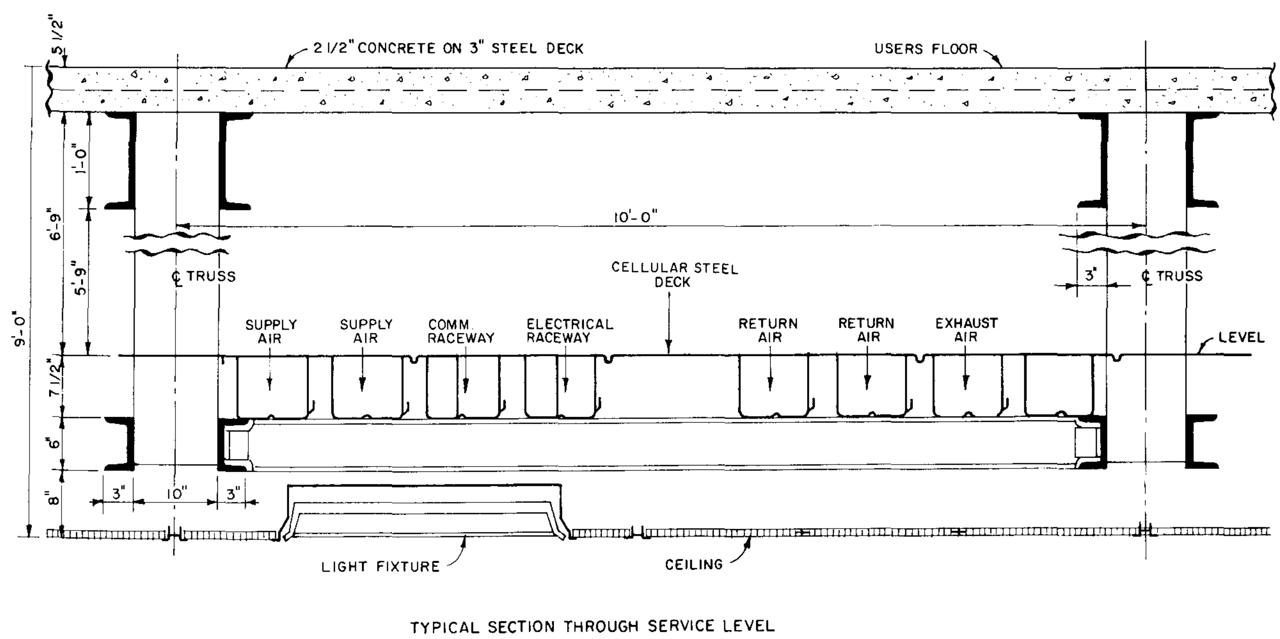


Figure 6. Cross-section through the cellular steel deck system employed in the interstitial design of the Good Samaritan Hospital in Dayton, Ohio.

steel deck eliminates the need for supplementary catwalks. Another of its significant advantages is that the cellular deck can be designed to serve as an integral component of the building's mechanical and electrical systems. Tested by Underwriters Laboratories, both two- and three-hour ratings have been obtained for the design. Additional particulars of this system may be obtained directly from either of the co-developers.

One of the important considerations in designing interstitial buildings is the combustibility of the materials within the interstitial space. Because such spaces have a large volume, it is possible for a sizable fire load to develop if combustible conduit, piping and ductwork are permitted. Therefore, all electrical wiring should be installed in steel conduit and all piping, ductwork, catwalks (for maintenance and service personnel) and other building service equipment should be constructed of noncombustible materials. Furthermore, the interstitial space should not be used for storage.

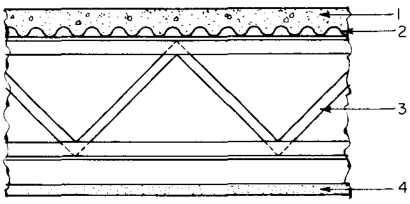
SUMMARY

Steel truss systems continue to be used in an increasing variety of building types. The reason is plain: Such framing concepts offer the designer an effective and economical means of achieving spatial flexibility, building maintenance efficiency, light-weight construction and fast erection.

Although fire-resistance ratings cannot be obtained from direct test results because of size limitation imposed by testing facilities, extrapolation of findings from tests on functionally similar structural members or assemblies permit the designer to develop effective fire-protection techniques that are acceptable to code authorities.

FIRE-RATED CONSTRUCTION SUMMARY†

FLOOR AND ROOF ASSEMBLIES
Steel Joists:
Membrane Ceiling Protection



BASIC CONSTRUCTION	RATING (hours)*	AUTHORITY REF.
1. Topping: Sand-gravel concrete Sand-limestone concrete Cinder concrete/topping Perlite-portland cement concrete Gypsum tiles Gypsum tiles with topping Gypsum concrete		
2. Forming: (where required) Metal lath** Formed steel Gypsum boards Paper-backed wire fabric		
3. Steel Joists: Open web types. See test reports for minimum size		
4. Ceilings:*** Acoustical tiles, concealed grid	1, 1½, 2, 3	UL-G000 series
Lay-in-panels, exposed grid	1, 1½, 2, 3	UL-G200 series
Metal pans with mineral wool	2	UL-G000 series
Gypsum wallboard	¾, 1, 1½, 2, 3	UL-G500 series
Mineral fibers: on gypsum lath	3	AIA
on metal lath	1½, 2, 2½	NBS-TRBM44
Mineral and fiber boards	2	AIA
Plasters on metal lath: Cementitious mixture	2	UL-G400 series
Neat gypsum	2½, 3	NBS-BMS92
Perlite-gypsum	3	AIA
Vermiculite-gypsum	4 2½, 3, 4	UL-G400 series NBS-BMS92
Sand-gypsum	1½, 2 3	NBS-BMS92 AIA
Sand-portland cement	1½	NBS-BMS92
Plasters on gypsum lath: Cementitious mixtures	¾, 1	UL-G500 series
Perlite-gypsum	1 1, 1½, 2, 2½, 3, 4	UL-G500 series NBS-BMS141

†From *Fire-Resistant Steel-Frame Construction*, AISI, 1974

*No differentiation is made here between restrained or unrestrained ratings.

**SJI Technical Digest No. 4, "Design of Fire-Resistive Assemblies with Steel Joists" published by Steel Joist Institute.

***For general information on permissible openings see Membrane Ceiling Openings on Page 52 of "Fire-Resistant Steel-Frame Construction."