Discussion

Fire Resistance of Protected Steel Columns

Paper presented by T. T. LIE and W. W. STANZAK (3rd Quarter, 1973 issue)

Discussion by **HENRY J. STETINA**

The development of a simple formula for computing fire endurance of protected steel columns is commendable. However, to qualify for building regulations, the formula should not only assure reliability with existing fire test performances, but also be adaptable for all commonly used protections. The latter requirement may be properly restricted to "lightweight" protections since the paper pointedly excludes "massive" type materials such as concrete encasements for which a solution is given elsewhere.

In addition the formula and applicable protections should be described in terms that are readily understood within the construction industry. The frequently implied exercise of judgment should be minimized because rather few architects, engineers, and building officials have the expertise of those specializing in fire resistance technology.

Undoubtedly the authors used data that disclosed the actual end endurance points of fire tested steel columns to establish the validity of computed fire resistance. Such detailed information is generally not readily accessible. Authorities* who publish lists of rated fire resistance construction simply give the accorded hours (no fractions) of fire resistance, thus disregard the fractional hour that may be actually achieved. In rare instances, ratings of one-half hour have been recognized.

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In the absence of detailed test reports, an investigation was made with reference to the 65 UL** rated column protections for which the formula is obviously applicable. The ratings cover both contour and box type designs. A C value of 0.5 was used for mineral fibers and 1.2 for cementious mixtures and plasters. In 41 cases the computed fire resistance exceeded the assigned hourly ratings; thus, they would be unconservative in those cases where the rating coincides with the end point reached in the test. A more realistic comparison may accrue by throwing out all differences up to one hour, thereby simulating the usual practice in establishing hourly ratings. Even so, there remain 23 cases where computed resistance exceeded the ratings by more than one hour, and of these, there are eight cases that exceeded two hours. Admittedly, a comparison of computed resistance with the actual endurance points could mitigate or even absolve this unfavorable appraisal of the authors' Eq. (17).

A favorable aspect, although based on the single reported case where identical protection was fire tested on columns of different size (W10 and W14), showed Eq. (17) to be reasonably accurate for translating fire resistance capability from one size steel column to another, either larger or smaller than the test size. Promulgating the formula for this one purpose probably warrants inclusion in building codes if it can be extended to cover all common light weight protections.

This implication that the formula may be too exclusive becomes apparent upon examining the entire field of current column protections. For example, according to the research paper, the formula is not applicable to gypsum boards. In effect, 60% of the 36 box type protections illustrated by UL are thereby excluded. Actually the percentage is greater, about 72%, because it seems logical to include in the non-applicable category those box protections where plaster is applied to gypsum lath or to gypsum wallboards. Should this be a false assumption and the formula declared relevant, then there arises

**"*Fire Resistance Index*" *Janurary 1972, Underwriters' Laboratories, Inc.*

questions as to proper density and thickness. There is, of course, no question where metal lath is used (the apparent intent of Fig. 1a.)

The formula seems to be based upon uniform thickness of protection on the four sides of box type constructions. Several rated designs show metal lath offset from the column flanges, with the space between lath and flange filled solid with plaster. If the formula is applicable, then there is a question as to the appropriate thickness. Should thickness of fill be ignored or the four sides averaged? Questions of this type are not resolved by engineering judgment.

Most plaster protections on box type designs consist of two coats, brown and scratch, with a different formulation for each coat. Obviously the densities are correspondingly different. Unfortunately UL *Fire Resistance Index*, as well as other rating authorities, does not publish densities of plasters. However, where known, an average density would be satisfactory—an engineering judgment.

Another material that seems to be excluded is the sand-gypsum and sand-cement plasters, probably relatively unimportant because these heavy materials are not as common today as in years gone by. They weigh about 120 pcf, whereas Eq. (17) was derived for materials whose densities are less than 50 pcf.

Of greater importance is the exclusion of intumescent coatings. This is unfortunate, because lightweight mastics are being used with greater frequency as time goes on. Currently, aside from two poineer column tests conducted at the National Bureau of Standards, there are five designs for protecting steel columns listed by Underwriters' Laboratories.

In addition to the scope of coverage, the definitions for terms used in the formula should be free of possible ambiguities. Consideration should be given to clarifying the following items.

The reference to perlite or vermiculite *per se* is confusing, because in the form used in the applicable constructions they are merely the aggregate component of a plaster composition. These materials should be identified only as commonly specified: perlite-gypsum, perlite-cement, etc. Since plasters usually contain gypsum or cement it follows that a C of 1.2 is intended. Therefore, the reference to these aggregates under C of 0.5 is misleading.

The words "chemically stable", without benefit of the entire research paper, are meaningless.

It is not clear just what form of "mineral wool" is intended. Only one case using mineral wool is reported by the several authorities issuing ratings. UL gives a rating for a box design using mineral wool batts or blankets. No density is reported. While this material merits inclusion, it does seem to be overemphasized in contrast with more popular materials that appear to be excluded.

In summary, it becomes evident that some further refinement is desirable before the formula is ready for acceptance by regulatory agencies. The following constructive steps are suggested:

1. Reliability of the proposed formula needs to be confirmed with regard to published rated column protections. Comparison using actual end endurance points of fire tests would, of course, afford a better measure of accuracy than using hourly ratings.
2. Avoid the discriminatory aspect by including other lightweight protections, particularly various wallboards, with and without plaster, and mastics.
3. Identify type of protection material as commonly stated on design drawings or in construction specifications. These could be tabulated with corresponding C values.
4. Include in the table the average density or a range of density for which the C value is appropriate. This will be most helpful, assuming density in a given problem is not known, for obtaining a rapid, reasonably accurate measure of fire resistance.
5. Minimize reliance upon so called engineering judgments; these can be a source of controversy.

Discussion by **T. T. LIE** and **W. W. STANZAK**

The authors wish to thank Mr. H. J. Stetina for his comments and constructive suggestions.

Mr. Stetina makes the particularly significant observation that authoritative test data normally used by architects and engineers often do not contain the complete information required to use the simple formula that was developed. However, as fire technology becomes a more developed engineering discipline, it is hoped that this situation will be improved.

Knowledge of heat transfer has progressed to the stage where classical fire protection problems, such as the heat flow from a fire into a protected steel column, can be reduced to theoretically nice solutions. Where the required input data are at hand (particularly physical properties of protective materials) and a considerable calculation facility (some form of modern high-speed digital computer) is available, these should result in better answers than the simple formula presented by the authors. It is doubtful that such precision can be justified in view of the assumptions inherent in contemporary methods of design for structural fire protection.

The authors agree that Eq. (17) is more suitable for calculations concerning variations in the "size and shape" factor, than for changes in thickness of protective cover. It was pointed out in the paper that $(l_1/l_2) = (J_1/J_2)^{1.25}$ is probably a more correct relation where the thickness of protective cover alone is a variable. The relatively short-time physical integrity of most common building materials makes it difficult to establish rigorous relationships that are valid for a wide range of fire endurance times. After the protective material has suffered significant physical deterioration due to the effects of fire, the applicability of any calculation method must cease to exist. This is why for long fire endurance periods, the calculated values are sometimes considerably in excess of those demonstrated by experiment. For common materials such as gypsum wallboards, Eq. (17) with a constant of 1.2 may be used, but provides conservative results. A W10×49 column with double layer ⅝-in. wallboard protection has a calculated fire endurance time of 123 min., but tested at 139 min.* A W14×228 section with a single layer of ½-in. wallboard received a 2 hr. ULI rating, but has a calculated fire endurance time of only 79 min. The calculation method seriously underestimates the fire resistance in the last case, because where the chemical reactions in wallboard are allowed to be completed, the "constant" for this material becomes considerably greater than 1.2. So the formula has a useful but very limited application to materials of this type, that is, the time range over which it applies with good accuracy with a given constant is relatively small.

With plaster protections it is reasonable to use an average thickness and density. However, where protection is decidedly unsymmetrical, such as a wide-flange column protected with double-layer wallboard over the web side, and only a single layer over the flange, averaging the thickness would be misleading. Where core spaces are filled with a non-structural materials, its heat capacity may be included as an equivalent steel weight added to W in Eq. (17).

Stanzak, W. W., Column Covers: A Practical Application of Sheet Steel as a Protective Membrane, DBR Fire Study No. 27, Ottawa, Feb. 1972, NRCC 12483.

The authors have conducted a preliminary investigation into the behavior of intumescent coatings and found that none of the presently used predictive methods, including Eq. (17), apply. Future research will likely develop a predictive capability for these materials as well, however.

The authors' reply to Mr. Stetina's summary of suggested constructive steps, in order:

1. Fire test data (using end point values) was examined only to the extent required to establish the validity of the semi-empirical Eq. (17). It is agreed that further examination of published test data is required to determine its merits and limitations for materials other than those specifically examined in the research work. Efforts in this direction are already actively proceeding under the sponsorship of the American Iron and Steel Institute.
2. Examination of a wide variety of protective materials was considered beyond the scope of the research work leading to preparation of this paper. It is expected that the additional work mentioned in (1) above should serve to overcome this criticism.
3. This is a valuable suggestion and should be acted on in building design practice.
4. This also is a valid suggestion. The authors further urge that authorities who publish fire test ratings include the average weight per foot of application, average thickness, and average density of protective materials in their listings or ratings. In addition, publication of the actual temperature end point of fire endurance should be included with the hourly rating classification.
5. The number and variety of variables (particularly the construction dependent ones) involved in the column fire resistance problem make it difficult to de-emphasize the importance of engineering judgement to solution of problems. However, it may be that as materials, application techniques, and adequacy of field inspection become more reliable, the need for use of engineering judgement will be largely eliminated.