DEVELOPMENT OF ROOM PRESSURE IN THE DISCHARGE OF FM-200®, COMPARED TO THE STRENGTH OF VARIOUS STRUCTURAL COMPONENTS

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ABSTRACT

Experimentation shows that room pressure development in an FM-200 discharge is highly dependent upon several system and environmental parameters. Factors such as enclosure construction, enclosure integrity (leakage), enclosure contents, initial enclosure temperature, fire size per room volume and agent flow rate, will all influence the development of room pressure during the discharge of an FM-200 system. A comparison between the pressure development scenarios reported in class A fire and non-fire experimentation and the strength of various structural elements is presented. Discussion of this comparison focuses on wall stud strength for applications typically protected by FM-200 systems: interior, non-load bearing framing, or partition studs. This analysis shows that the pressures developed during discharge of an FM-200 system are less than the yield strengths of structural members generally used in applications protected by FM-200 systems.

I. *INTRODUCTION*

It has long been agreed that knowledge of enclosure integrity is an essential element in the design of fire protection systems. **NFPA** influenced integrity testing for Halon 1301 (and now all halocarbon agents) and CO_2 systems are evidence of this need. These guidelines focus on the verification of adequate hold times for the agent to maintain a pre-determined concentration level and agent height interface within the enclosure.

While maintaining agent concentration for an extended period of time is an important design consideration, there has been little published information regarding the relationship between agent pressure development during discharge, and its affect on enclosure integrity. Variations in the expected level of enclosure integrity could affect the ability of the suppression system to achieve and maintain a desired agent concentration.

Fenwal, Inc.[1] reported the results of Halon 1301 discharges in a **770** ft^3 enclosure in, *Pressure and temperature measurements resulting from a halon 1301 discharge into a simulated computer room.* Halon discharges were done at a concentration of 7% *v/v*. Leakage rates were not reported, but maximum concentration measurements were at or above **6.9%** *v/v* for all measurements. Results indicate a maximum negative room pressure of between **3** and 5 *psf.*

Senecal and Prescott[2] developed an empirical model for negative room pressure development during an FM-200 discharge in a tightly sealed enclosure with no fire. A conservative heat

PROGRAM	ROOM VOLUME ft^3	CONSTRUCTION*	LEAKAGE in'	CONCENTRATION(S) % v/v	FIRE SIZE(S) kW
1	2560	2x4 stud with gyp.	NOT MEASURED	7	0-23
2	2560 512	2x4 stud with gyp.	12 15	7	0-36
3	3000 & 3400	2×4 stud with gyp. & cinder block	25 - 55⁺	7, 8, 9	0

III. Experimental Results

FIGURE 1 shows results from programs (1) and (2), as the relationship between the, maximum pressure developed in the enclosure (positive and negative) in *psf*, and the fire size, in *kW* (grouped as shown). Each fire size range represents the mean of approximately **5-14** tests, The

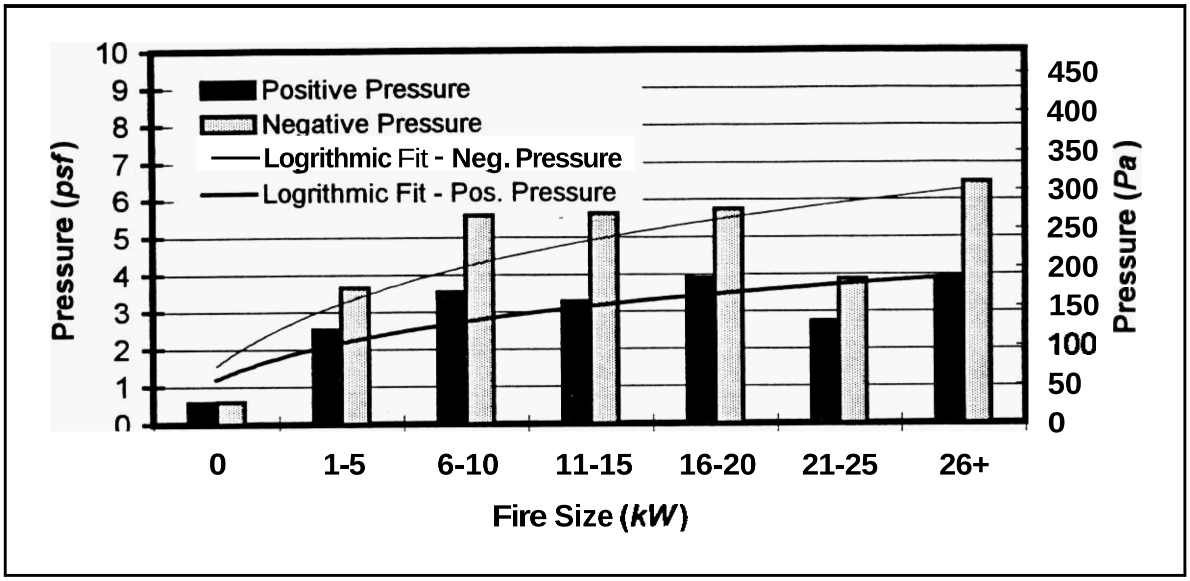
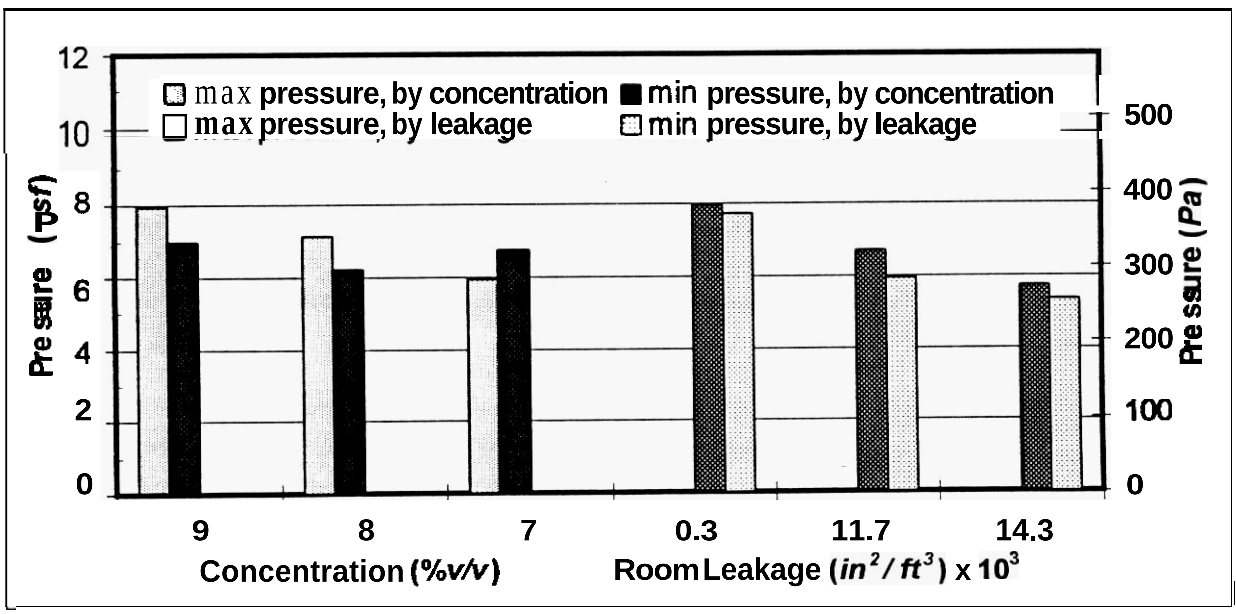


FIGURE 1. Room pressure vs. fire size - Programs (1) & **(2)**



of Program (3). Each bar indicates the mean of approximately 3-4 tests. As expected, positive room pressure development varies fairly uniformly with concentration and leakage area. However, negative room pressure does not vary significantly with concentration, but shows a decreasing trend, with respect to increasing leakage area.

Additionally, the results from the cinder-block enclosure portion of Program (3) show an unmistakable trend, when compared to the wood-gypsum enclosure results. TABLE 2 shows a comparison of the pressure development results for each enclosure type, by concentration. The data shows a consistently larger pressure development for the cinder-block construction, for all concentrations. This trend is evidence of the flexibility and 'breathability' of the wood-gypsum construction.

C% v/v	WOOD P_{POS} psf	C-BLOCK P_{POS} psf	Difference	WOOD P_{NEG} psf	C-BLOCK P_{NEG} psf	Difference
9.0	7.99	11.22	+40.4%	6.98	10.33	+48.0%
8.0	7.15	8.28	+15.8%	6.21	9.12	+46.8%
7.0	5.96	6.40	+7.4%	6.77	8.48	+25.3%

IV. STRUCTURAL MEMBERS

Over 90% of the applications of FM-200 involve the protection of class A hazards. Many of these applications are single enclosures, within larger buildings or structures. As such, distinctive design requirements and standards are employed in the construction of these facilities. *The BOCA National Building Code/1993*[7] makes the following distinction: "*Loadbearing wall:* A wall supporting any vertical *load* in addition to its own weight. *Nonloadbearing wall:* A wall which does not support vertical *loads* other than its own weight." Typically, applications that are protected by FM-200 systems, fall into the category of nonloadbearing construction. Additionally, many local standards may require the use of fire rated building materials in fire suppression applications, providing additional strength, not quantified in this research. The properties and geometry of materials used in nonloadbearing applications are not required to provide significant structural strength. Subsequently, the study of a nonloadbearing structure is a conservative, and therefore desirable approach to the analysis of a simple room pressurization scenario, free of external loadings and forces.

Materials employed in the construction of the enclosures mentioned above can vary significantly. Several factors influence the construction material employed in an FM-200 protected space: building age, *cost* of construction and materials, required schedule of completion of construction, availability of materials, architectural and contractor design preferences, and others. The most common material used is light steel while some wood (various species) studs are also used.

	AVAILABLE	*in*	*in⁴*
212ST	25, 22, 20	2%	0.105, 0.155, 0.178
358ST ✧	25, 22, 20✧	3%	0.247, 0.367, 0.422
400ST	25, 22, 20	4	0.302, 0.463, 0.533
362CSJ	20, 18, 16, 14	3%	0.530, 0.681, 0.863, 1.066
362CSN	20, 18, 16, 14	3%	0.435, 0.564, 0.690, 0.858

Yield Strength, all steel studs = 33,000 *psi*

✧ Unimast reports 75% of interior applications utilize the 358ST25; 20% use the 358ST20

* I, = Moment of Inertia about the x axis

Wood products

Many residential and older commercial structures employ the use of wood studs for interior partitioning and framing. TABLE 4 shows the physical properties of various wood studs, typically used in interior framing applications.

WOOD SPECIES	NOMINAL *in*	TYPICAL* *in*	I_x*, BY TYPICAL DIMENSION *in⁴*	TENSILE STRENGTH *psi*
Fir	2×4, 2×6	1½×3½, 1½×5½	5.35, 20.74	300
Douglas Fir	2×4, 2×6	1½×3½, 1½×5½	5.35, 20.74	340
Spruce	2×4, 2×6	1½×3½, 1½×5½	5.35, 20.74	710
Yellow Pine	2×4, 2×6	1½×3½, 1½×5½	5.35, 20.74	470

Analysis

Computation of bending stress in structural members:

P	Room pressure	*psf*
M	Bending moment	*lb-ft*
rw	Room width	*ft*

s	Stud spacing, Typically **1.0, 1.33,** or **2.0**	*ft*
h	Room height	*ft*
w	distributed load (on each *stud)*	*lb/ft*
c	maximum distance from neutral axis of structural member to farthest edge	*ft*
E	Elastic Modulus	lb/ft^2
I_x	Moment of Inertia	ft^4
σ	Bending stress	lb/ft^2

The distributed load on any given *stud is* determined by a **known** pressure within an enclosure, multiplied by the spacing of the structural **studs:**

$$w = \frac{\dfrac{(P) \times (r\,w \cdot h)}{\left(\dfrac{r\,w}{s}\right)}}{h} = P \cdot s \quad \left\{\frac{lbf}{ft}\right\} \qquad (1)$$

Equation (1) assumes that 100% of the pressure loading is absorbed by the wall studs. In this conservative approach, no additional strength is accounted for by wall finishing materials. Maximum bending moment is determined for the typical beam configuration, fixed end supports:

$$M_{fixed} = \frac{w}{12}(6\ell x - 6x^2 - \ell^2) \quad \{lbf \cdot ft\} \qquad (2)$$

$x = \frac{1}{2}h$ and $\ell = h$ for maximum bending moment:

$$M_{fixed} = \frac{wh^2}{24} \quad \{lbf \cdot ft\} \qquad (3)$$

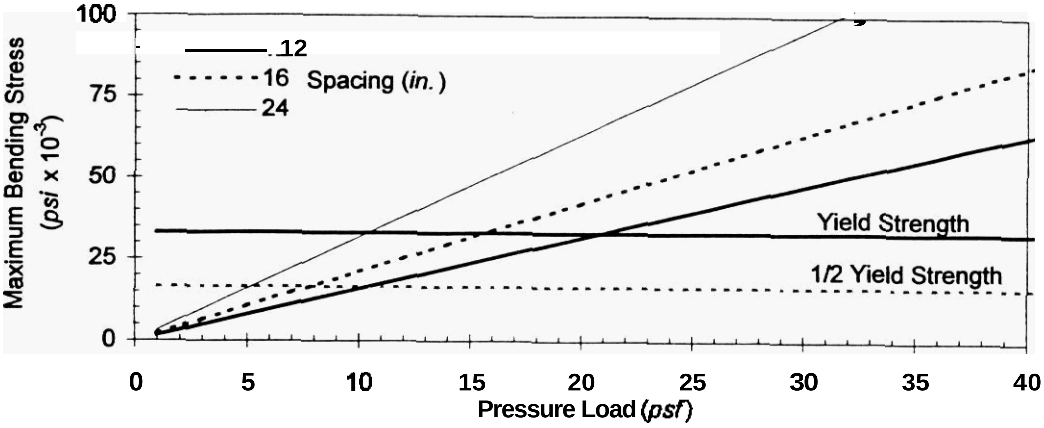
Maximum bending stress is determined from the maximum bending moment calculated above:

$$\sigma = \frac{M_{fixed}\,c}{I_x} \quad \{lbf \cdot ft^2\} \qquad (4)$$

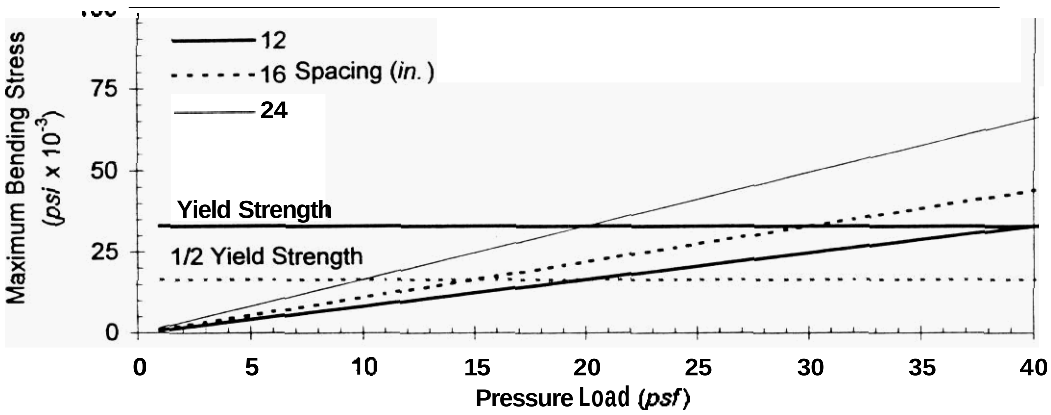
Graphs

Graphical representations of structural member stress vs. enclosure pressure loading are presented, in **FIGURES 3** through 6. Stud height is shown at 16 *ft* height for the 'ST' steel studs (conservative), 20 ft height for the 'CSN' steel studs and 12 *ft* height for wood studs. Stud spacing is represented by three lines on each graph, for 12 in, 16 *in* (most common), and **24 *in*** spacing. Lines are shown to indicate the critical stress property of the material.

Interior Steel Stud Stress vs. Room Pressure
25 gauge, 76 ft height



Interior Steel Stud Stress vs. Room Pressure
22 gauge, 76 ft height



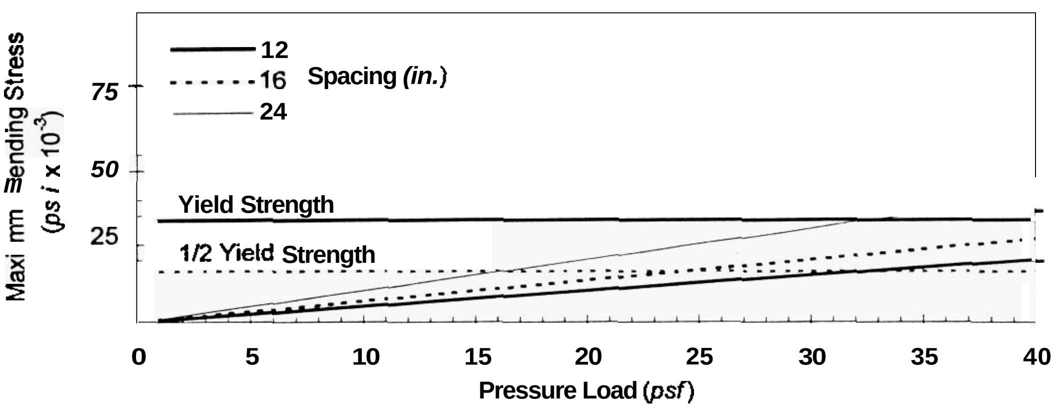


FIGURE 3: Unimast 212ST stud

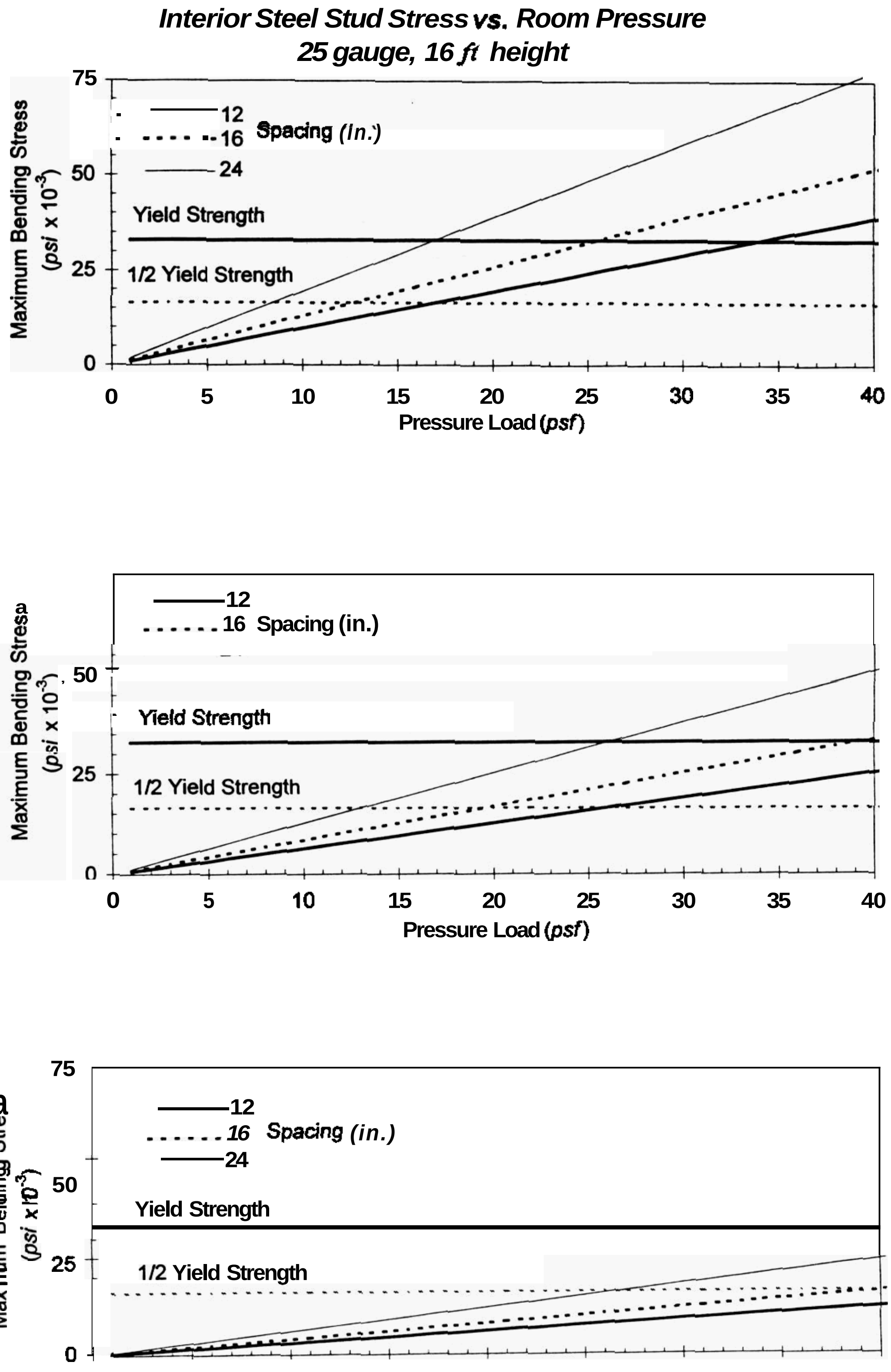
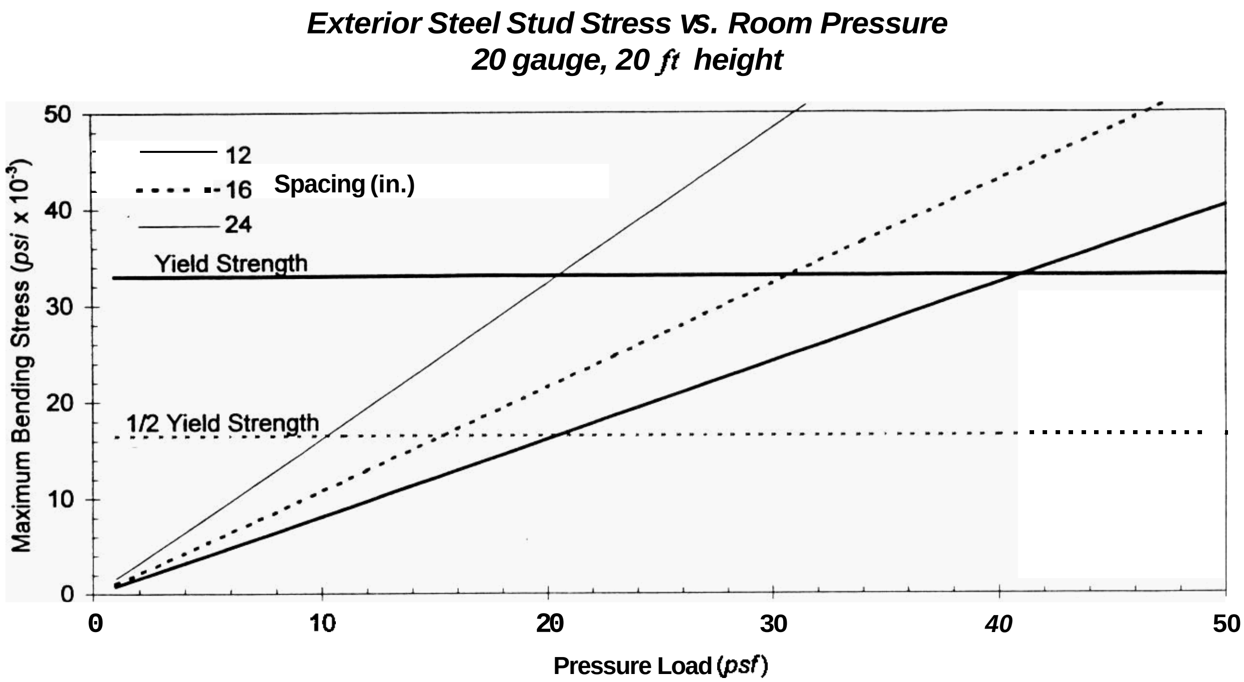


FIGURE 4: Unimast 358ST stud



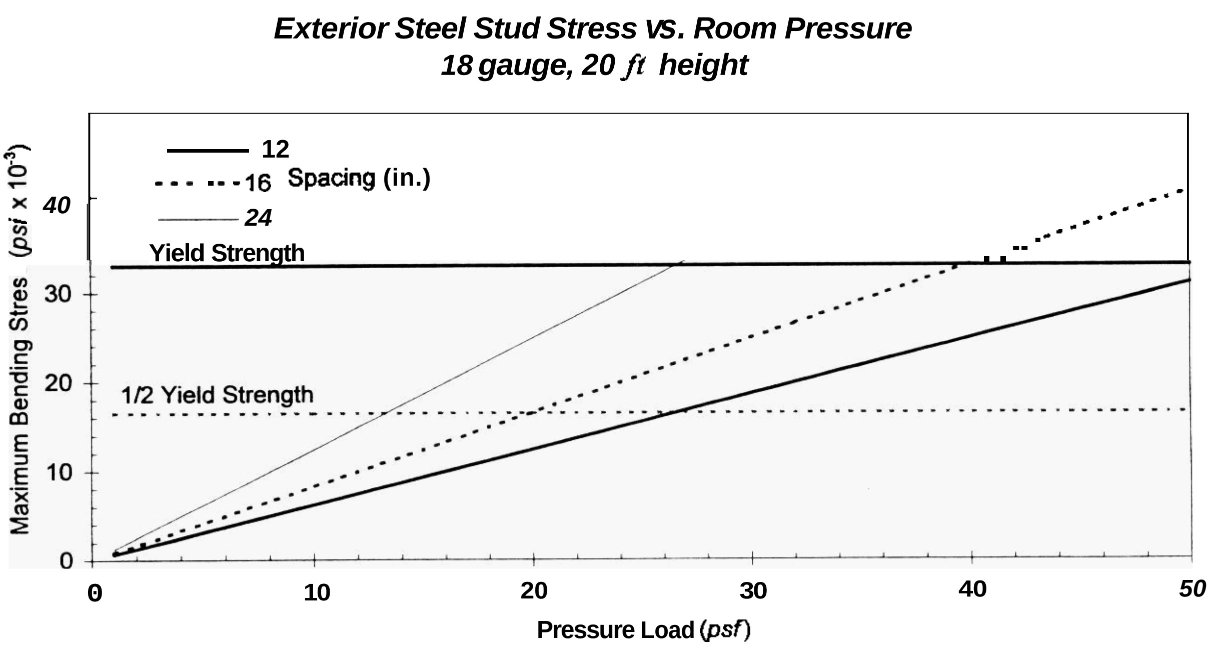
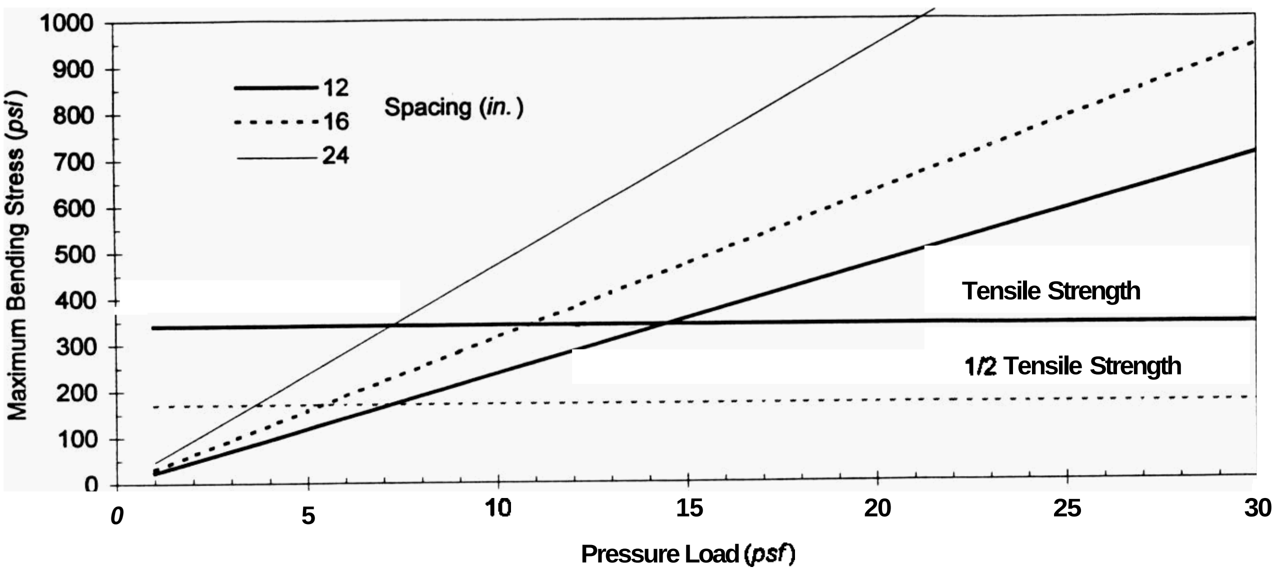


FIGURE 5: Unimast 362CSN stud

Wood Stud Stress vs. Room Pressure
2 x 4, 12 ft height



Wood Stud Stress vs. Room Pressure
2 x 6, 12 ft height

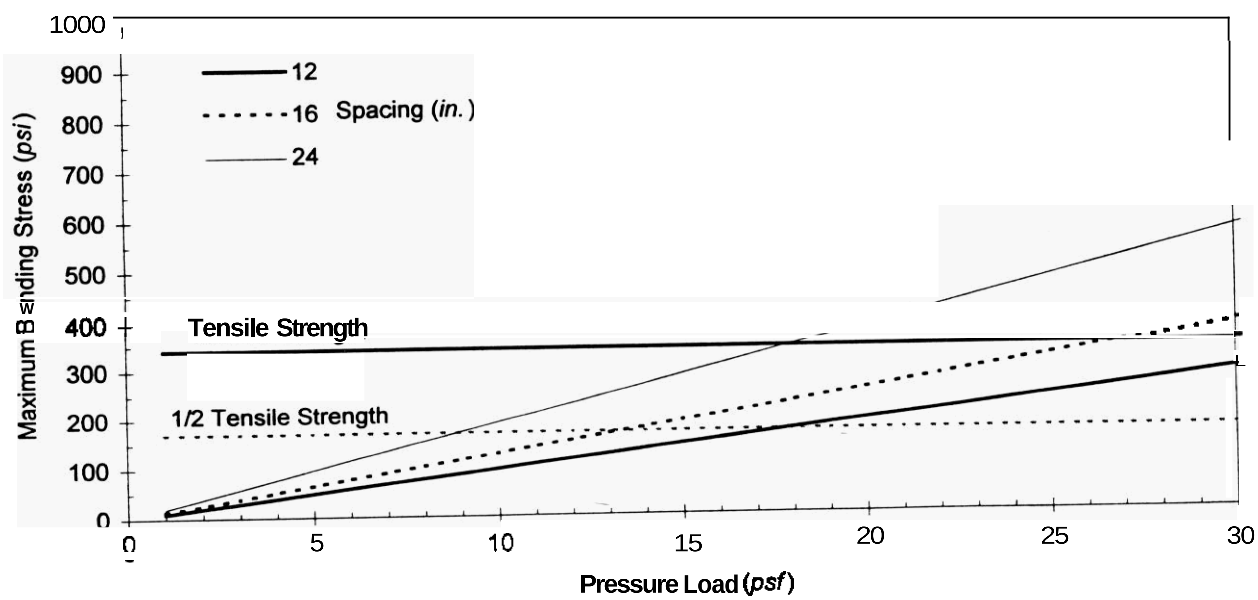


FIGURE 6: Douglas Fir

V. Discussion of Experimental Results and Structural Members

Experimental results show peak pressure development in a variety of FM-200 discharge configurations to range between ~0 *psf* and 8 *psf* (383 Pa). Both positive and negative pressure development have been shown to attain this level for various testing configurations. Although positive and negative pressure development represents slightly different concerns to a specific end-user, for this analysis and because wall finishing systems typically use horizontal-force-supporting screws, either positive or negative room pressure can be represented as completely absorbed by the wall structural members.

Unimast Incorporated has indicated that up to 95% of their interior, partition framing applications utilize the 3⅝ *in* stud, at either 20 or 25 gauge steel. FIGURE 4 shows these particular configurations, at the top and bottom of the page. In both cases, considering a typical stud spacing of 16 *in*, the yield strength of the material is not exceeded until a room pressure development of over 25 *psf*.

Wood structural members show slightly different characteristics when considering room pressure development. For typical 2x4 construction, with 16 *in* spacing shown in FIGURE 6, the tensile strength of the material is not exceeded until ~11 *psf* (527 Pa). FIGURE 6 also shows 2x6 construction, with a stress reduction of approximately 146%, for all three spacings reported. Additionally, this analysis is extremely conservative and does not consider the added strength provided by wall finishing systems such as gypsum board or plywood.

VI. Conclusions

From the data that is presented in this research, the following conclusions have been drawn:

1. In modeling a typical application for an FM-200 fire suppression system, experimentation considering various leakage, concentrations and class A fire scenarios shows maximum absolute room pressure development at or below approximately 8 *psf* (383 Pa).
2. The yield strength of typical steel construction members and construction geometries in typical FM-200 fire suppression system applications, is greater than the typical bending stress produced by the pressure generated in an FM-200 discharge, as reported above.
3. The tensile strength of typical wood construction members in typical FM-200 fire suppression system applications, is greater than the typical bending stress produced by the pressure generated in an FM-200 discharge, as reported above.

VII. FUTURE WORK

Additional data and investigation is warranted on a variety of other construction materials, including composite walls, concrete and masonry, and various finishing materials. Also, additional investigation into the strength of various wall components can be justified. Specifically, doors and windows have unique strength and flexibility characteristics that require additional, individual examination.

It has been shown in this and previous research that a completely sealed enclosure may provide indefinite agent hold times, but may also present unacceptable levels of pressure development. A challenge exists to meet these two requirements simultaneously. Ideally, an end user requires a) adequate agent hold time and b) sufficient safety to ensure no damage to the structural integrity of the enclosure. A standard can be developed, where both conditions (hold time and structural integrity) are satisfied.

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