National Exams Dec. 2012

07-Bld-A7, Building Envelope Design

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is a CLOSED BOOK EXAM.
   Casio or sharp calculator allowed

3. FIVE (5) questions constitute a complete exam paper.
   The first five questions as they appear in the answer book will be marked.

4. Each question is of equal value.

5. For questions that require an answer in essay format, clarity and organization of the answer are important.

6. Equations and data required for calculations are provided in the appendix of this exam booklet.

Question 1 (20 marks)

A 2x6 wood-frame brick veneer wall is made up of the following components:

- 100mm exterior brick (RSI 0.13)
- 25mm air space (RSI 0.22)
- one layer of Tyvek weather-barrier membrane, 0.2mm
- 12.5 mm plywood sheathing (RSI 0.11)
- 140mm glass fiber insulation (RSI 3.67)
- 6 mil polyethylene as vapour and air barrier
- 12.5mm gypsum board (RSI 0.08)

The interior surface resistance is RSI 0.12 and the exterior surface resistance is RSI 0.03. The indoor conditions are kept at 22°C dry-bulb and 30%rh and the average outdoor temperature in January is at -10°C for Toronto.

1) Calculate the effective RSI value of the wall assembly using Parallel method. The wood stud spacing is 16" at centre, and assume the thermal conductivity of the wood stud is 0.11W/m•K. The actual dimension of 2x6 wood stud is 38mm by 140mm.
2) Although polyethylene is used as air barrier, the contractor did not seal well the penetrations i.e. electric outlet, as a result air exfiltrates through the wood-frame walls. Would there be any condensation within the wall assembly due to air exfiltration? If so, where would the condensation occur? How would you suggest avoiding the problem if you were to re-design the wall assembly? Support your solution with calculations.

Question 2 (20 marks):

Part A (5 marks)

In a four-story wood-frame multi-unit residential building built in Vancouver, a back-sloped flashing was noticed at the second floor where the brick veneer is in transition with fiber-cement cladding, as shown in photo 1. 1) Explain what could have caused this problem. 2) What should have been done to prevent this?

Photo 1

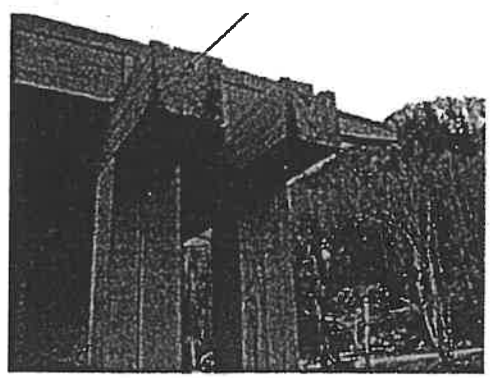


Photo 2

Part B (5 marks)

As shown in photo 2, the end section of a wooden beam experienced serious deterioration. 1) Explain the cause and mechanism that led to this deterioration. 2)what should have been done to prevent this?

Part C (5 marks)

Explain the failure mechanism shown in photo 3 and how to reduce the risk of such failures.

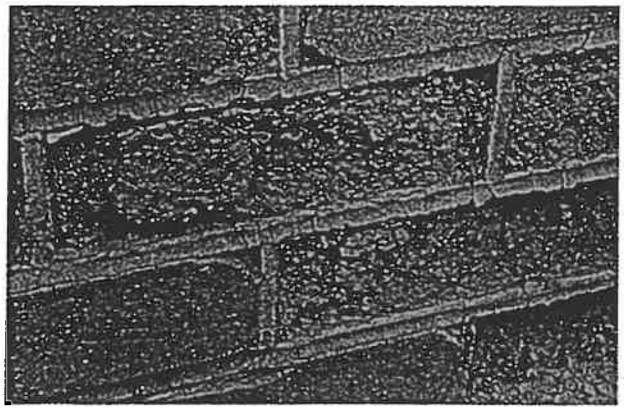


Photo 3

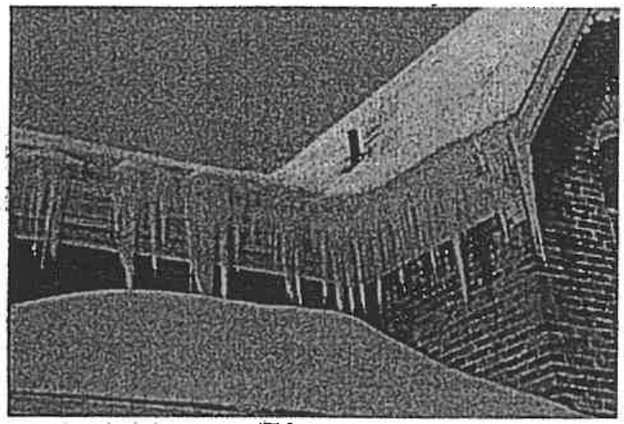


Photo 4

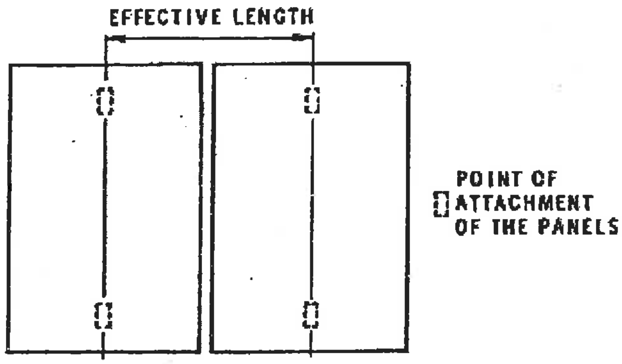
Part D (5 marks)

In photo 4, note that icicles are formed at the eaves of a sloped roof. Explain what has caused it and how to avoid such a problem.

Question 3 (20marks)

Five-meter wide, dark gray, precast concrete spandrel panels are to be used on a building with allowance made for lateral expansion and contraction. The panels are anchored at the middle point, as shown in the Figure below. This building is located in Toronto.

1) What is the maximum surface temperature experienced by the concrete panel? Assume the wall receives 600W/m^2 solar radiation in a summer day with outdoor temperature of 32°C. The soar absorptivity of the dark gray surface is 0.8 and the outdoor heat transfer coefficient is 20W/m^{2o}C for a calm day.
2) What is the maximum movement this concrete panel experiences? Assume the design winter temperature is -22°C. The coefficient of linear thermal expansion and contraction of concrete is 11.0 x10^{-6}/°C.
3) What would be the minimum vertical joint width if a sealant having a movement capacity of ±20% is proposed and the sealant is applied at the mean temperature.
4) Sketch the vertical joint, label the components and the relative dimensions (joint width and depth), and explain the function of each component.



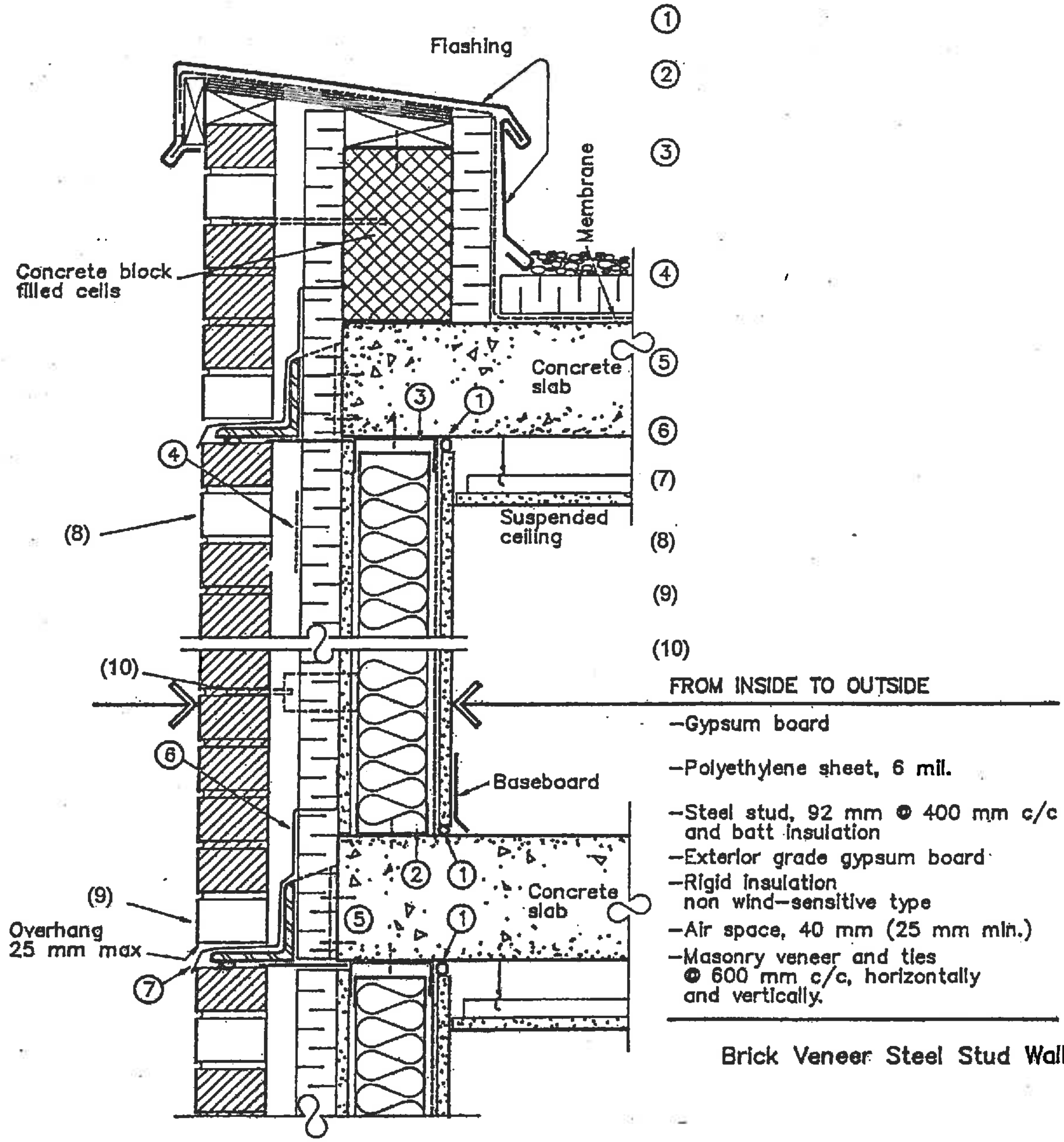
(a) PANELS FIXED AT MID-POINT

Question 4 (20 marks):

Part A: (10 marks)

Figure below shows a vertical cross-section of a brick veneer cavity wall with steel stud.

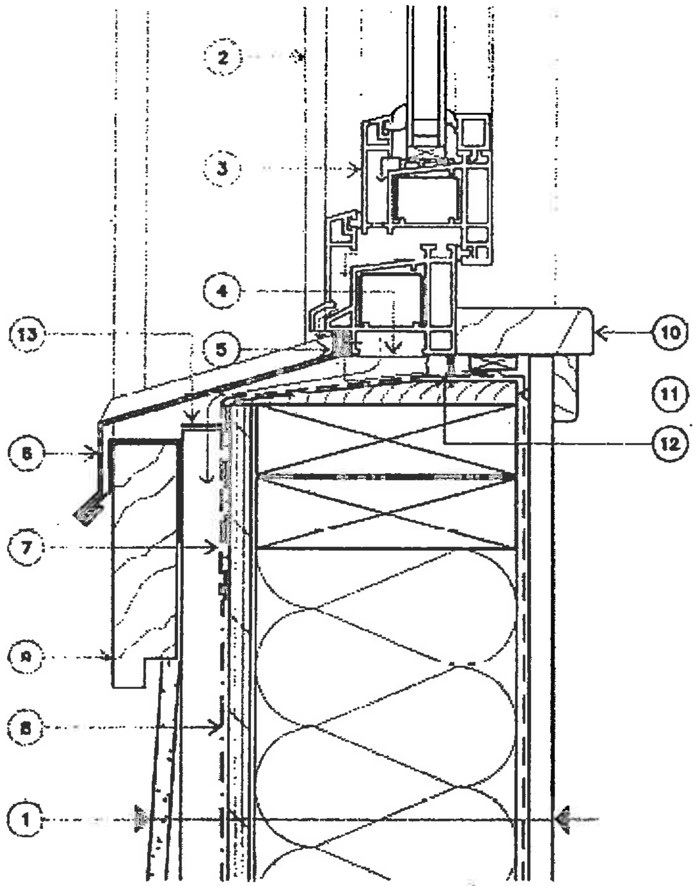
a. Label all the components and explain the function of each component.
b. Mark the air barrier on the drawing and list the elements that form the air barrier system in this case.
c. Explain why a soft joint is normally required between the top of the brick veneer and the bottom of the shelf angle supporting the bricks of the next storey in a multi-story building.



Brick Veneer Steel Stud Wall

Part B (10 marks)

Figure below shows a typical window/wall connection detail. Explain how the rainwater is managed in this design.



LEGEND

1. Wall Assembly
   Cladding (cementitious siding)
   19mm (¾") wood strapping (p.t.)
   Vapour permeable sheathing membrane
   Sheathing
   Wood framing 38x140mm (2x6) with batt insulation
   Polyethylene
   Gypsum board
2. Sealant beyond
3. Window assembly
4. Intermittent shim
5. Sealant
6. Pre-finished metal flashing with end dam
7. Foil-face membrane
8. Vapour permeable sheathing membrane
9. Exterior wood trim
10. Interior window trim
11. Sloped blocking
12. Sealant & backer rod
13. Insect screen

Question 5 (20 marks)

Design a low-slope, exposed membrane roofing assembly for a warehouse building located in Toronto. The primary membrane is to be Modified Bitumen (SBS).
1) Sketch the roof section and label the main components
2) Draw a roof plan and show the location of drainage and the detailing of drainage
3) List the potential failures of a low-slope roof with Modified Bitumen membrane and elaborate on how to prevent these failures.

Question 6 (20 marks)

Review the case "Frame shortening" and with the aid of sketches to explain the failure mechanisms and how to prevent such failures from occurring.

Appendix: equations

- Vapor flow equation:

$$W = MA\theta(p_1 - p_2) \tag{1}$$

where:

W = total mass of vapor transmitted, ng

M = permeance coefficient, ng/(s·m^2·Pa), $M = \frac{\overline{\mu}}{l}$

θ = time during which flow occurs, s

l = thickness, m

$\overline{\mu}$ = average permeability, ng/(s·m·Pa)

A = cross-section area of the flow path, m^2

$(p_1 - p_2)$ = vapor pressure difference applied across the specimen, Pa.

- Conductive heat transmission equation

$$\frac{q}{A} = U(t_i - t_o) \tag{2}$$

where

q/A = heat-flow rate, W/m^2

U = overall coefficient of heat transmission, W/(m^2·K)

t_i, t_o = inside and outside temperature, K

- Thermal resistance of composite section

$$R = \frac{1}{U} = R_1 + R_2 + R_3 \tag{3}$$

- Average U-value by parallel method (area-weighted average)

$$U = \frac{A_1}{A_1 + A_2}U_1 + \frac{A_2}{A_1 + A_2}U_2 \tag{4}$$

- Solar air temperature on vertical surfaces

$$t_e = t_o + \frac{\alpha I}{h_o} \tag{5}$$

where,

t_e=solar air temperature, in °C

t_o=outdoor air temperature, in °C

α, solar absorptance;

I, solar radiation intensity, in W/m^2;

h_o, the exterior surface heat transfer coefficient, W/m^2°C

- Humidity ratio

$$W = \frac{p_w}{p_a} \times 0.622 = \frac{0.622 p_w}{p_t - p_w} = \frac{0.622 \times RH\% \times p_{sat}}{p_t - RH\% \times p_{sat}} \tag{6}$$

p_w=partial water vapour pressure, Pa

p_{sat}=saturated water vapour pressure at temperature °C, Pa
p_t=atmospheric pressure, 101325Pa at sea level;

- Density

$$\rho_a = \frac{p_a}{R_a T} \quad , R_a=287.1 \text{ J/(kg·K)} \qquad (7)$$

$$\rho_w = \frac{p_w}{R_w T} \quad , R_w=461.5 \text{ J/(kg·K)} \qquad (8)$$

- Conversion from volume flow to mass flow

$$m = \frac{L}{\upsilon}$$

where, L is volume flow, m^3/s;
υ is specific volume, kg/m^3.

- Dimension change due to thermal expansion

$$\Delta L = C_t \times L \times \Delta t$$

$$J_t = \Delta L / S_m \qquad (9)$$

where, C_t is the coefficient of linear thermal expansion, in $10^{-6}/°C$;
L is the effective length of panel, m
Δt is the temperature differential, °C
S_m is the sealant movement capacity, %
J_t is the width of the joint, m.

Table 1

Water-Vapour Pressures at Saturation at Various Temperatures over Plane Surfaces of Pure Water and Pure Ice

Temp., °C	Pressure, Pa Over ice	Pressure, Pa Over water	Temp., °C	Pressure, Pa Over ice	Pressure, Pa Over water	Temp., °C	Press., kPa	Temp., °C	Press., kPa
−50	3.935	6.409	−22	85.02	105.4	5	0.8719	33	5.031
−49	4.449	7.124	−21	93.70	115.0	6	0.9347	34	5.320
−48	5.026	7.975	−20	103.2	125.4	7	1.001	35	5.624
−47	5.671	8.918	−19	113.5	136.6	8	1.072	36	5.942
−46	6.393	9.961	−18	124.8	148.8	9	1.147	37	6.276
−45	7.198	11.11	−17	137.1	161.9	10	1.227	38	6.626
−44	8.097	12.39	−16	150.6	176.0	11	1.312	39	6.993
−43	9.098	13.79	−15	165.2	191.2	12	1.402	40	7.378
−42	10.21	15.34	−14	181.1	207.6	13	1.497	41	7.780
−41	11.45	17.04	−13	198.4	225.2	14	1.598	42	8.202
−40	12.83	18.91	−12	217.2	244.1	15	1.704	43	8.642
−39	14.36	20.97	−11	237.6	264.4	16	1.817	44	9.103
−38	16.06	23.23	−10	259.7	286.3	17	1.937	45	9.586
−37	17.94	25.71	−9	283.7	309.7	18	2.063	46	10.09
−36	20.02	28.42	−8	309.7	334.8	19	2.196	47	10.62
−35	22.33	31.39	−7	337.9	361.8	20	2.337	48	11.17
−34	24.88	34.63	−6	368.5	390.6	21	2.486	49	11.74
33	27.69	38.18	5	401.5	421.5	22	2.643	50	12.33
−32	30.79	42.05	−4	437.2	454.5	23	2.809	51	12.96
−31	34.21	46.28	−3	475.7	489.8	24	2.983	52	13.61
−30	37.98	50.88	−2	517.3	527.5	25	3.167	53	14.29
−29	42.13	55.89	−1	562.3	567.8	26	3.361	54	15.00
−28	46.69	61.39	0	610.8	610.8	27	3.565	55	15.74
−27	51.70	67.27	+0.01	Triple point of water		28	3.780	56	16.51
−26	57.20	73.71	1	—	656.6	29	4.006	57	17.31
−25	63.23	80.70	2	—	705.5	30	4.243	58	19.15
−24	69.85	88.27	3	—	757.5	31	4.493	59	19.02
−23	77.09	96.49	4	—	812.9	32	4.755	60	19.92

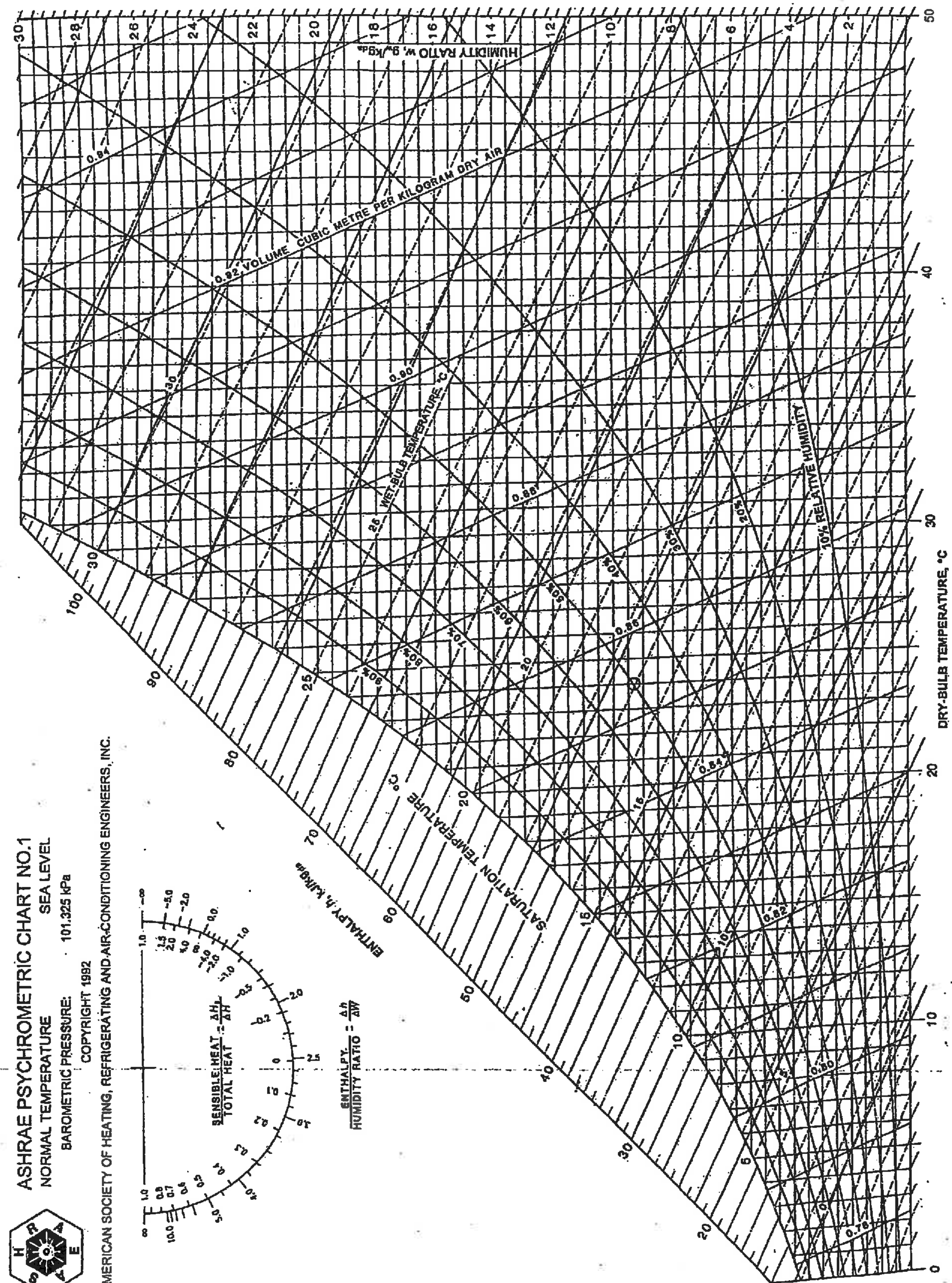
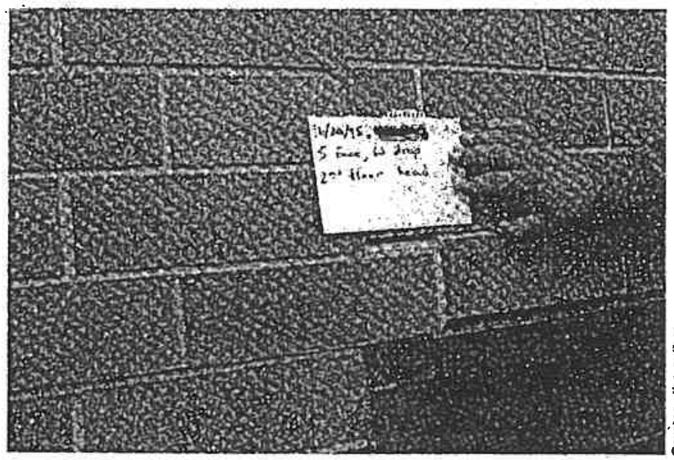


Fig. 1 ASHRAE Psychrometric Chart No. 1

Frame Shortening



Courtesy the author

The 24-story tower was constructed in 1983 and, shortly after being occupied, suffered severe distress in the exterior brick masonry veneer. The timing and accumulation of distress toward the bottom of the tower as shown in the photo are both characteristic manifestations of the failure mechanism: frame shortening.

The tower frame was constructed of conventionally reinforced cast-in-place concrete columns and post-tensioned floors. Although it is well known that concrete shrinks over time, it is not often recognized that the resultant shortening of a tall building frame can wreak havoc on the exterior curtain wall if not accommodated in the design.

> The majority of the strain occurs early in the life of the structure.

By David H. Nicastro

Causes of Distress

In the photo, notice that the courses are out of alignment across the vertical expansion joint (at card); this is most evident in the top mortar joint. Also, the shelf angle no longer supports the masonry to the right of the expansion joint, except for the one brick that has fallen down to rest on it.

When constructed, the masonry was fully seated on the shelf angles, and the courses were in alignment. Tremendous in-plane forces have distorted the steel angles and translated the prism of masonry downward to the left of the expansion joint, leaving the masonry to the right behind. Other distress included spalled and cracked brick units, stair-step cracks through the masonry, and out-of-plane displacement and rotation of entire masonry panels.

Column shortening is caused not only by shrinkage, but creep and elastic compression as well. Applying the dead load from the construction of each additional floor causes the columns below to compress and then to creep over time, in addition to continuing to shrink due to hydration of the portland cement. While creep and shrinkage continue indefinitely at an ever-decreasing rate, the majority of the strain occurs early in the life of the structure.

Although the top floor is displaced the greatest vertical distance from its intended position (each floor below contributes some), the greatest individual column shortening occurs at the lowest floor. Because the shelf angles are anchored to the building frame, the lower floors squeeze the masonry, accounting for the characteristic accumulation of distress at these floors.

If horizontal expansion joints are incorporated below each shelf angle, they can accommodate frame shortening as well as other in-plane masonry movements. Unfortunately, no horizontal joints were specified in this project.

The calculations to quantify the amount of frame shortening (either as a prediction for design or as an analytical estimate in a forensic study) are extremely complex, involving many embedded equations. Frame shortening is a function of the time of placement, curing, volume/surface ratio, and amount of reinforcing of each column as well as the time of application of each additional load (floors constructed above). We used a multidimensional array to input all of the detailed data and perform these calculations for this project, which confirmed that the strains were excessive. ◆

DAVID H. NICASTRO, P.E., founder and president of Engineering Diagnostics, Inc., in Houston, Texas, specializes in the investigation and remedy of construction problems and the resolution of related disputes.