# *Seismic Design of Masonry The Theory, The Codes and The Practice*

John G Tawresey
KPFF Consulting Engineers [Retired]

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## *Contents:*

1. The Theory [ASD and SD]
2. The Code [2012 IBC, ASCE 7 –10 and TMS 402-11]
3. The Examples

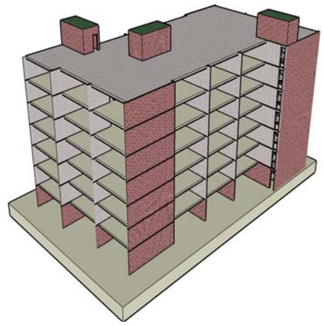


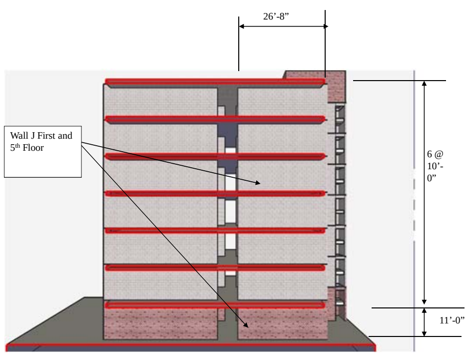
## Trial Design 4

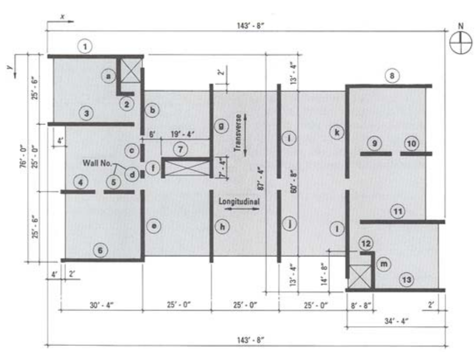
Seven Story Apartment Building

Size: 76,500 S.F

Seven Story Apartment Building





- Design Problem Statement:
  - **Design the wall J of the apartment at the base and the 5th floor.**
  - **Complete the design questionnaire at the end of the problem.**
  - **Assume a rigid diaphragm.**
  - **Assume the wall is a special reinforced masonry shear** wall.
- Materials:
  - **Concrete Masonry (different strengths can be used at the base and 5th floor).**
  - **Grade 60 reinforcement.**
- Design Code:
  - **2006 IBC and ACI 530.1-05/ASCE 6-05/TMS 602-05 (2005 MSJC) Strength**

Design Loads:

- Seismic Design Category D, R = 5.0, Ω0 = 3.0, Cd = 3.5, T = .50 sec. SDS = 1.12. SD1 = .68

Dead and live loads given.

Dead load includes partition and wall weight. The axial load is due to minor coupling in the model. It is not the Ev (vertical earthquake load).

**Fee Paid = $750.00**

**Average = 8.4 hours**

**2 hour minimum to 16 hours max**

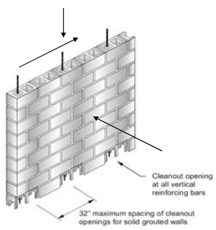
**Average $ 89.28/hour**

**Experience varied from 2 to 30 years**

| Problem # 4 | | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Education | MS | MS | MS | MS | MS | MS |
| Years w/ building design | 10 | 3 | 20 + | 3 - 10 | 0 - 3 | 3 - 10 |
| Total years since BS | | 3 | 20 + | 3 - 10 | 0 - 3 | 3 - 10 |
| Experience W/ design masonry | | None | Many | Many - no SD | None | Few |
| How many hours | | 16 | 12 | 10 | 2 | 8 |
| Masonry strength at first | 1500 | 1500 | 2200 | 2500 | 2500 | 2500 |
| Wall Thickness | 8" | 8" | 8" | 12" | 8" | 8" |
| Trim steel at first | none | | (6) # 5 | (4) # 6 | none | (1) # 7 |
| Vertical reinforcement at first | # 4 @ 40 | # 4 @ 24 | # 5 @ 32 | # 5 @ 24 | # 4 @ 16 | # 4 @ 32 |
| Horizontal reinforcement at first | (2) # 5 @ 40 | # 4 @ 24 | (2) # 4 @ 48 | (2) # 4 @ 40 | # 4 @ 8 | (2) # 4 @ 32 |
| Max Axial at first | 862 | 712 | 787 | 871 | 1133 | 838 |
| Min Axial at first | 379 | 512 | 512 | 387 | 807 | 371 |
| Axial for maximum | Not checked | Not checked | Not checked | Not checked | Not checked | Not checked |
| Factored moment at first | 6175 | 6175 | 6175 | 6175 | 6175 | 6175 |
| Factored shear at first | 143 | 143 | 143 | 143 | 143 | 143 |



Most Masonry Design is about bending plus compression in walls – in-plane or out-of-plane




W,H,L

In-Plane

$b \Rightarrow W$

$d \Rightarrow L$

Out-of-Plane

$b \Rightarrow L$

$d \Rightarrow W$



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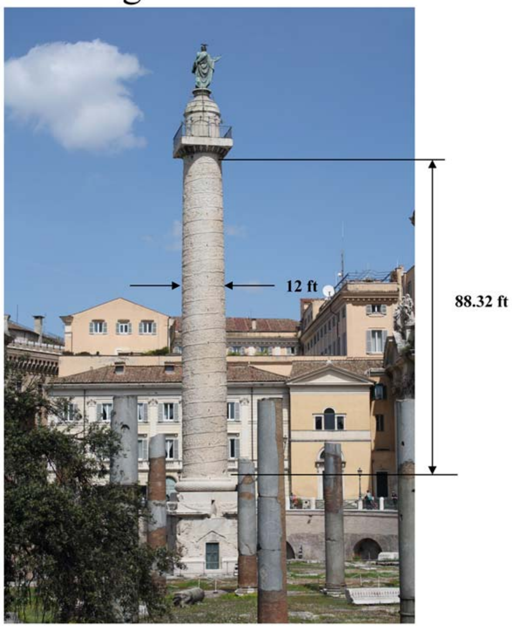
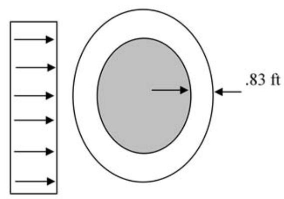
# Tragans Column




If the column walls are .83 ft [10 in] thick, will the tower tip over in a 36 psf wind load applied to the projected area?

- Neglect the weight above the 88.32 ft
- Consider the base at the bottom of the 88.32 ft

Assume the column is constructed of marble weighing 150 pcf

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## Tragans Column


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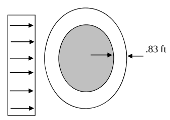





## Tragans Column

| | |
|---|---|
| Projected Area:<br>88.32x12 = 1060 ft²<br>Wind Load:<br>1060x36 = 38,200 Lb<br>Center of Pressure:<br>Assume located at the mid-height<br>H = 88.32/2 = 44 ft | This seminar is not about loading, particularly wind. Consult ASCE 7 for more detailed analysis.<br>Note: Circular sections wind loading includes positive pressure on the windward face due to stagnation and negative pressure on the leeward side due to air shedding. They are additive. We are just assuming the 25 psf which is conservative.<br>Note: If the diameter of the column were small enough, such as a flag pole, the phenomenon of vortex shedding could occur resulting in oscillations that could lead to metal fatigue. |
| Overturning Moment:<br>38,200x44 = 1,681,000 lb-ft | The wind is pushing to overturn the column |



## Tragans Column

| | |
|---|---|
| Column Weight<br>3.14x[6²-5.17²]x88.3x150 = 385,600 lbs | The resisting moment comes from gravity.<br>$\pi[R_1^2 - R_2^2]*H*165$ |
| Resisting Moment:<br>385,600x6 = 2,313,000 lb-ft | Assume the weight acts at the center of the circular cross section. If it was a odd cross section, the center of mass would need to be calculated using the first moment of inertia. |
| 2,313,000 – 1,681,000 = 632,000 lb-ft | Since the resisting moment exceeds the overturning moment, the column remains upright. |

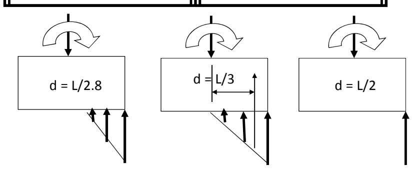
## Tragans Column

| PL/2/M = Pd/M<br>2,313,000 /1,681,000 = 1.4 | Overturning moment/Resisting moment = F.S |
|---|---|



## Tragans Column

| PL/2/M = Pd/M<br>2,313,000 /1,681,000 = 1.4<br>M/PL = 1/2.8 | Overturning moment/Resisting moment = F.S |
|---|---|




Pd/M = 1.4 Pd/M = 1.5 Pd/M = 1.0

F.S. = 1.4 F.S. = 1.5 F.S. = 1.0



## Tragans Column

**How much additional axial load is required to reach a F.S of 1.5?**

**M/PL = 1/3.0**

**3*1,681,000/12 = 420,200 lbs**

**Dead load = 385,600 Lbs**

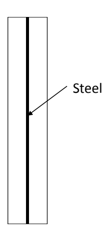
**Added = 420,000 – 385,600 = 34,400 lbs**

**1 No. 7 bar**

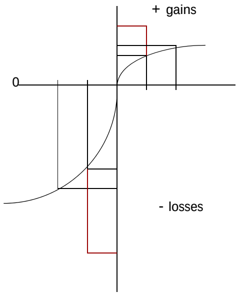
**Use .9D load factor**

**420,000 - .9*385,600 = 73,000 Lbs**

**212% increase**



## Expected Utility Theory Vs Prospect Theory




Instabilities around 0

Gains and losses are not symmetrical

"Losses loom larger than gains"

Estimates people tend to dislike losses about twice as much as they like equivalent gains

"Aggregate Losses; Segregate Gains"



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***The Problem – Seismic Design of Walls***

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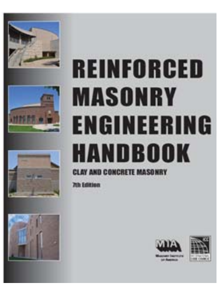
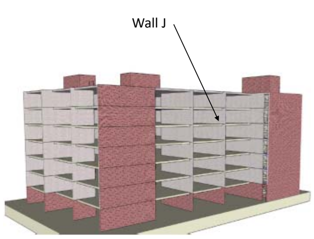
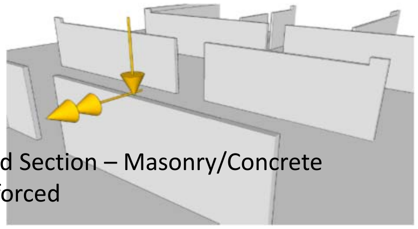


***The Problem – Seismic Design of Walls***

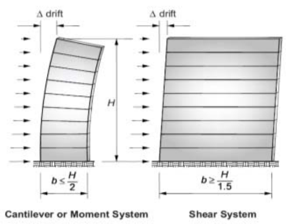
Bending + Compression



Cracked Section – Masonry/Concrete reinforced



***The Problem – Seismic Design of Walls***




| Story | Seismic Moment - K-ft | Dead Load | F.S. [PL/2]/M |
|---|---|---|---|
| 7 | 136 | 55.2 | 5.23 |
| 6 | 558 | 136.3 | 3.16 |
| 5 | 1223 | 217.4 | 2.30 |
| 4 | 2065 | 298.4 | 1.87 |
| 3 | 3069 | 379.5 | 1.60 |
| 2 | 4263 | 460.6 | 1.40 |
| 1 | 5897 | 543.7 | 1.19 |

Add axial load at L [trim steel].

75k at L results in F.S. of 1.5

Requires 1.2 $in^2$ of reinforcement.



***The Equations:***

**The Assumptions**

**The Variables and Solution for the Unknowns**

**The Limits**

## *The Equations -Assumptions:*

**Plane Sections Remain Plane [Special Case of an Isotropic Material]**

**Strains are Compatible**

**Stress and Strain are Related**



## *The Equations -Assumptions:*

**Hooks Law**

$$\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{yz} \\ \varepsilon_{zx} \\ \varepsilon_{xy} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16} \\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} & S_{26} \\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} & S_{36} \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} & S_{46} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} & S_{56} \\ S_{61} & S_{62} & S_{63} & S_{64} & S_{65} & S_{66} \end{bmatrix} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{yz} \\ \sigma_{zx} \\ \sigma_{xy} \end{bmatrix},$$



## *The Equations -Assumptions:*

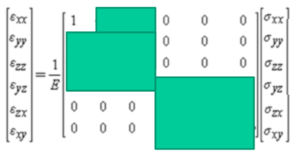
**Hooks Law –Isotropic Material**

$$\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{yz} \\ \varepsilon_{zx} \\ \varepsilon_{xy} \end{bmatrix} = \frac{1}{E} \begin{bmatrix} 1 & -\nu & -\nu & 0 & 0 & 0 \\ -\nu & 1 & -\nu & 0 & 0 & 0 \\ -\nu & -\nu & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1+\nu & 0 & 0 \\ 0 & 0 & 0 & 0 & 1+\nu & 0 \\ 0 & 0 & 0 & 0 & 0 & 1+\nu \end{bmatrix} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{yz} \\ \sigma_{zx} \\ \sigma_{xy} \end{bmatrix}$$

*The Equations -Assumptions:*

**Plane Sections Remain Plane [Special Case of an Isotropic Material]**

**Hooks Law –Plane Sections Remain Plane**

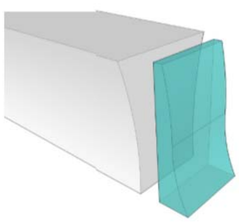


$$\in_{xx} = \frac{1}{E}\sigma_{xx}$$



*The Equations -Assumptions:*

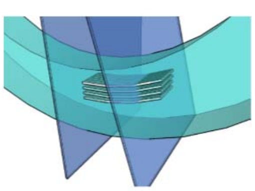
**Hooks Law –Plane Sections do not Remain Plane**





*2.1 The Equations -Assumptions:*

**Hooks Law –Plane Sections Remain Plane**



## *The Equations -Assumptions:*

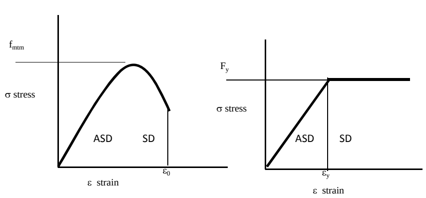
**Strains are Compatible**

**The strain in the masonry/concrete equals the strain in the reinforcement.**



## *The Equations -Assumptions:*

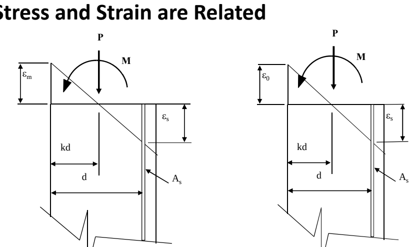
**Stress and Strain are Related**






## *The Equations -Assumptions:*

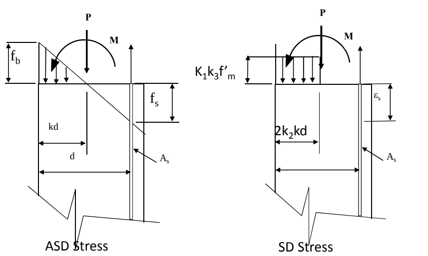
**Stress and Strain are Related**




ASD Strain SD Strain

*The Equations -Assumptions:*

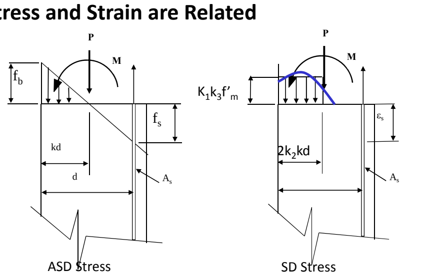
**Stress and Strain are Related**






*The Equations -Assumptions:*

**Stress and Strain are Related**






**The Variables and Solution for the Unknowns**

**Knowns:**

**Guess and Check: $A_s$,L,b,d**

**Loads: M,P and V**

**Unknowns:**

**Stresses: k, $f_b$, $f_s$ or k, $\epsilon_m$, $\epsilon_s$**

## The Variables and Solution for the Unknowns

**Equations:**

**Plane Sections Remain Plane**

**$\Sigma$F = 0, Internal to external**

**$\Sigma$M = 0, Internal to external**



## The Variables and Solution for the Unknowns

**Equations:**

**Plane Sections Remain Plane**

$$\frac{\varepsilon_m}{\varepsilon_s} = \frac{k}{1-k}$$



## The Variables and Solution for the Unknowns

**Equations:**

**Limits: The Steel Strain is 0**

**k = 1.0** **k = 1.0**

$$\frac{M}{Pd} = \left(\frac{2}{3} - \Delta\right) \qquad \frac{M}{Pd} = \left[1 - k_2 - \Delta\right]$$

## The Variables and Solution for the Unknowns

**Equations:**

**Limits: Stress in the steel – Special Case for SD**

**$F_s < f_y$**

$$k = \frac{\varepsilon_0}{\left(\varepsilon_0 + \frac{F_y}{E_s}\right)}$$

$$\frac{M}{Pd} = \frac{k_1 k_3 2k_2 kbdf'_m\left(1 - \frac{2k_2 k}{2}\right)}{\left(k_1 k_3 2k_2 kbdf'_m - A_s F_y\right)} - \Delta$$

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## The Variables and Solution for the Unknowns

**Equations:**

**Limits: Wall is not Cracked**

k = L/d k = L/d

$$\frac{M}{Pd} = \left(1 - \frac{L}{3d} - \Delta\right) \qquad \frac{M}{Pd} = \left(1 - \frac{k_2 L}{d} - \Delta\right)$$

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## The Variables and Solution for the Unknowns

**Equations:**

**ΣF = 0, Internal to external**

$$E_m \varepsilon_m \frac{bkd}{2} - E_s A_s \varepsilon_s = P \qquad k_1 k_3 f(\varepsilon_m) 2k_2 kdb = f(\varepsilon_s) A_s + P$$

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## The Variables and Solution for the Unknowns

**Equations:**

**$\Sigma$F = 0, Internal to external**

$$\varepsilon_{mo} = \frac{P}{E_m bd}$$

$$n = \frac{E_s}{E_m} \qquad \rho = \frac{A_s}{bd}$$

$$k^2 + \left(2n\rho + 2\frac{\varepsilon_{mo}}{\varepsilon_s}\right)k - \left(2n\rho + 2\frac{\varepsilon_{mo}}{\varepsilon_s}\right) = 0$$

Add a limit: Steel yielding

$$\varepsilon_s E_s = F_y$$

$$k = \frac{\left(A_s F_y + P\right)}{2k_2 k_1 k_3 bdf'_m}$$

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## The Variables and Solution for the Unknowns

**Equations:**

**$\Sigma$M = 0, Internal to external**

$$E_s \varepsilon_s A_s d\left(1 - \frac{k}{3}\right) = M - P\left(d - \frac{kd}{3} - \Delta d\right)$$

$$\frac{\varepsilon_{m0}}{\varepsilon_s} = \frac{n\rho\left(1 - \frac{k}{3}\right)}{\left(\frac{M}{Pd} - \left(1 - \frac{k}{3} - \Delta\right)\right)}$$

Add a limit: Steel yielding

$$M = A_s F_y\left(1 - \frac{2k_2 k}{2}\right)d + P\left(1 - \frac{2k_2 k}{2} - \Delta\right)d$$

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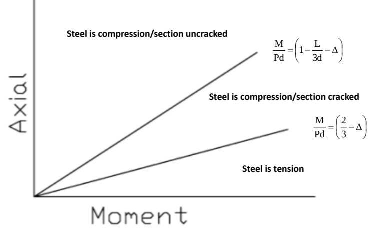
## The Variables and Solution for the Unknowns

***ASD***

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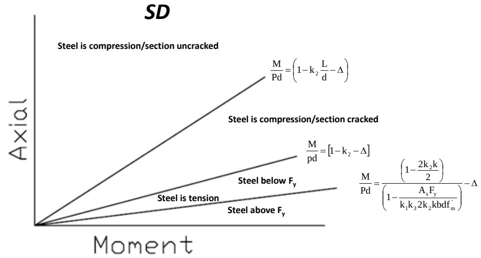
## The Variables and Solution for the Unknowns

***SD***

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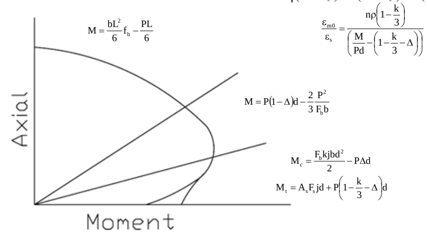
## The Variables and Solution for the Unknowns

$$k = \sqrt{\left(n\rho + \frac{\varepsilon_{m0}}{\varepsilon_s}\right)^2 + 2\left(n\rho + \frac{\varepsilon_{m0}}{\varepsilon_s}\right)} - \left(n\rho + \frac{\varepsilon_{m0}}{\varepsilon_s}\right)$$

$$\frac{\varepsilon_{m0}}{\varepsilon_s} = \frac{n\rho\left(1 - \frac{k}{3}\right)}{\left(\frac{M}{Pd} - \left(1 - \frac{k}{3} - \Delta\right)\right)}$$

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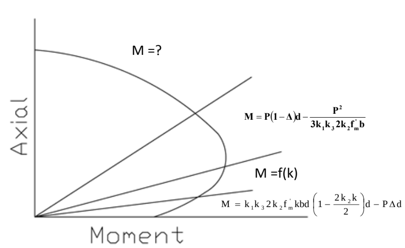
## *2.2* The Variables and Solution for the Unknowns

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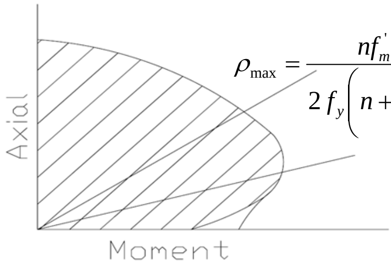
## Ductility Requirements and the Codes

**Axial Load is the same as reinforcement**

**Masonry ASD**

$$\rho_{\max} = \frac{n f_m^{'}}{2 f_y \left( n + \frac{f_y}{f_m^{'}} \right)}$$

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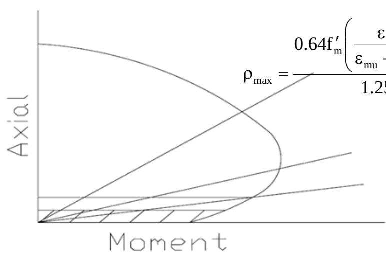
## Ductility Requirements and the Codes

**Axial Load is the same as reinforcement**

**Masonry ASD**

$$\rho_{\max} = \frac{0.64 f_m' \left( \frac{\varepsilon_{mu}}{\varepsilon_{mu} + \alpha \varepsilon_y} \right) - \frac{P_{ue}}{bd}}{1.25 f_y}$$

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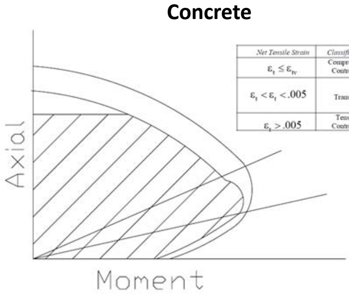
## Ductility Requirements and the Codes

**Axial Load is the same as reinforcement**

**Concrete**

| *Net Tensile Strain* | *Classification* | $\Phi$ |
|---|---|---|
| $\varepsilon_t \le \varepsilon_{ty}$ | Compression Controlled | .65 |
| $\varepsilon_t < \varepsilon_t < .005$ | Transition | $.65 + .25 \frac{(\varepsilon_t - \varepsilon_{ty})}{(.005 - \varepsilon_{ty})}$ |
| $\varepsilon_t > .005$ | Tension Controlled | .90 |

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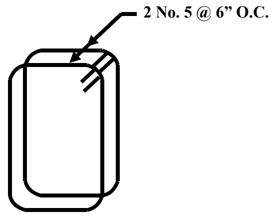
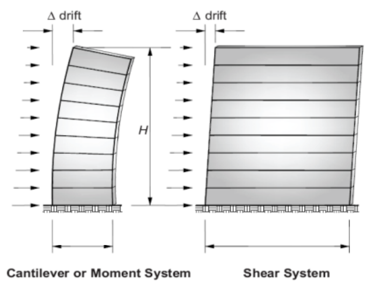
**What is wrong with this detail?**



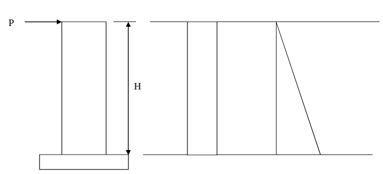



***One More Thing – Distribution of Loads***

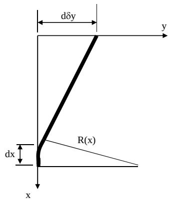





***Distribution of Loads***



### *Distribution of Loads - Flexure*




$$\frac{dx}{R(x)} = \frac{d\delta_y}{x} \quad \text{or} \quad d\delta_y = \frac{x\,dx}{R(x)}$$

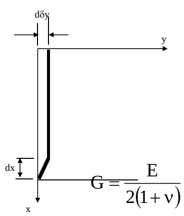
$$\frac{1}{R(x)} = \frac{\varepsilon(x)}{y} \qquad \varepsilon = \varepsilon_0 \frac{x}{H}$$

$$d\delta_y = \frac{\varepsilon_0}{yH} x^2 dx$$

$$\delta_y = \frac{\varepsilon_0}{yH}\int_0^H x^2 dx = \frac{\varepsilon_0}{y}\frac{H^2}{3} \qquad \varepsilon_0 = \frac{Mc}{EI} = \frac{PH\frac{L}{2}}{\frac{E}{12}TL^3} = \frac{6PH}{ETL^2} \qquad \delta_y = \frac{6PH^2}{ETL^2\frac{L}{2}}\frac{H^2}{3} = \frac{P}{ET}\left[4\left(\frac{H}{L}\right)^3\right]$$



### *Distribution of Loads - Shear*




$$\frac{dy}{dx} = \frac{P}{GTL}$$

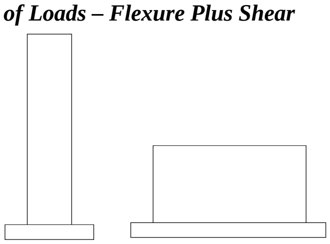
$$y = \frac{P}{GTL}\int dx = \frac{PH}{GTL}$$

$$G = \frac{E}{2(1+\nu)} \qquad \nu = .3$$

$$y = \frac{P}{GTL}\int dx = \frac{P}{GT}\left[\left(\frac{H}{L}\right)\right] = \frac{P}{ET}\left[2.6\left(\frac{H}{L}\right)\right]$$

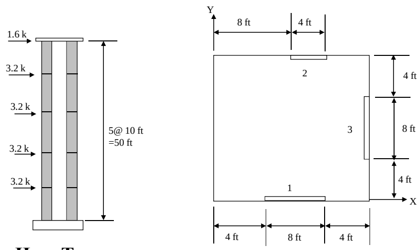


### *Distribution of Loads – Flexure Plus Shear*



$$\delta_y = \frac{P}{ET}\left[4\left(\frac{H}{L}\right)^3 + 2.6\frac{H}{L}\right]$$

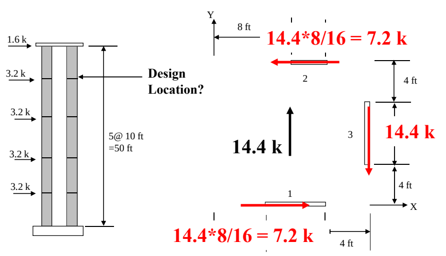
## *Distribution of Loads – Example*




**Hose Tower – Wind Load**

March 13, 2017 International Masonry Institute - Hawaii 43

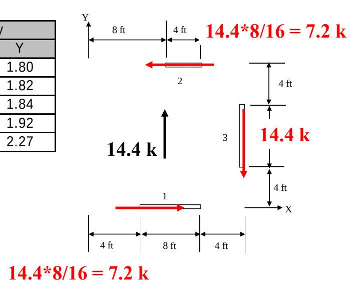
## *Distribution of Loads – Example*




March 13, 2017 International Masonry Institute - Hawaii 44

## *Distribution of Loads – Example*

| Center of Rigidity | | |
|---|---|---|
| | X | Y |
| Roof | 15.99 | 1.80 |
| 4th | 15.99 | 1.82 |
| 3rd | 15.99 | 1.84 |
| 2nd | 15.99 | 1.92 |
| 1st | 15.99 | 2.27 |




March 13, 2017 International Masonry Institute - Hawaii 45

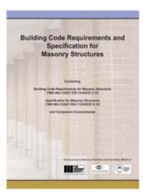
## *Contents:*

1. The Theory [ASD and SD]
2. The Code [2012 IBC, ASCE 7 –10 and TMS 402-11]
3. The Examples



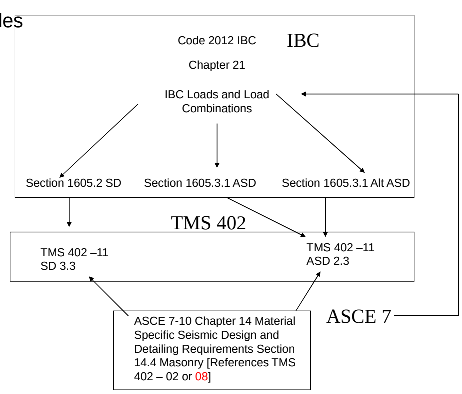
## Codes








## Codes



## Codes

**1605.2 Load combinations using strength design or load and resistance factor design.** Where strength design or load and resistance factor design is used, buildings and other structures, and portions thereof, shall be designed to resist the most critical effects resulting from the following combinations of factored loads:

$1.4(D+F)$ **(Equation 16-1)**

$1.2(D+F) + 1.6(L+H) + 0.5(L_r \text{ or } S \text{ or } R)$ **(Equation 16-2)**

$1.2(D+F) + 1.6(L_r \text{ or } S \text{ or } R) + 1.6H + (f_1 L \text{ or } 0.5W)$ **(Equation 16-3)**

$1.2(D+F) + 1.0W + f_1 L + 1.6H + 0.5(L_r \text{ or } S \text{ or } R)$ **(Equation 16-4)**

$1.2(D+F) + 1.0E + f_1 L + 1.6H + f_2 S$ **(Equation 16-5)**

$0.9D + 1.0W + 1.6H$ **(Equation 16-6)**

$0.9(D+F) + 1.0E + 1.6H$ **(Equation 16-7)**

where:

March 13, 2017 International Masonry Insititute - Hawaii 4

## Codes

**1605.3 Load combinations using allowable stress design.**

**1605.3.1 Basic load combinations.** Where *allowable stress design* (working stress design), as permitted by this code, is used, structures and portions thereof shall resist the most critical effects resulting from the following combinations of loads:

$D + F$ **(Equation 16-8)**

$D + H + F + L$ **(Equation 16-9)**

$D + H + F + (L_r \text{ or } S \text{ or } R)$ **(Equation 16-10)**

$D + H + F + 0.75(L) + 0.75(L_r \text{ or } S \text{ or } R)$ **(Equation 16-11)**

$D + H + F + (0.6W \text{ or } 0.7E)$ **(Equation 16-12)**

$D + H + F + 0.75(0.6W) + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$ **(Equation 16-13)**

$D + H + F + 0.75(0.7E) + 0.75L + 0.75S$ **(Equation 16-14)**

$0.6D + 0.6W + H$ **(Equation 16-15)**

$0.6(D+F) + 0.7E + H$ **(Equation 16-16)**

Note

March 13, 2017 International Masonry Insititute - Hawaii 5

## Codes

IBC 2012 Section 1605.3

5. In Equation 16-16, 0.6 $D$ is permitted to be increased to 0.9 $D$ for the design of special reinforced masonry shear walls complying with Chapter 21.

March 13, 2017 International Masonry Insititute - Hawaii 6

Codes

ASCE 7 -10 Section C2.4.1

Exception 3 given for special reinforced masonry walls, is based upon the combination of three factors that yield a conservative design for overturning resistance under the seismic load combination:

1. The basic allowable stress for reinforcing steel is 40% of the specified yield.
2. The minimum reinforcement required in the vertical direction provides a protection against the circumstance where the dead and seismic loads result in a very small demand for tension reinforcement.
3. The maximum reinforcement limit prevents compression failure under overturning.

Of these, the low allowable stress in the reinforcing steel is the most significant. This exception should be deleted when and if the standard for design of masonry structures substantially increases the allowable stress in tension reinforcement.

March 13, 2017 International Masonry Insititute - Hawaii 7

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Codes

**1605.3.2 Alternative basic load combinations.** In lieu of the basic load combinations specified in Section 1605.3.1, structures and portions thereof shall be permitted to be designed for the most critical effects resulting from the following combinations. When using these alternative basic load combinations that include wind or seismic loads, allowable stresses are permitted to be increased or taken equal to zero.

| | |
|---|---|
| $D + L + (L_r \text{ or } S \text{ or } R)$ | **(Equation 16-17)** |
| $D + L + 0.6\,\omega W$ | **(Equation 16-18)** |
| $D + L + 0.6\,\omega W + S/2$ | **(Equation 16-19)** |
| $D + L + S + 0.6\,\omega W/2$ | **(Equation 16-20)** |
| $D + L + S + E/1.4$ | **(Equation 16-21)** |
| $0.9D + E/1.4$ | **(Equation 16-22)** |

March 13, 2017 International Masonry Insititute - Hawaii 8

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Codes – ASCE 7

**2.1 GENERAL [ASCE 7 2005]**

Buildings and other structures shall be designed using the provisions of either Section 2.3 *[SD]* or 2.4 *[ASD]*. Either Section 2.3 or 2.4 shall be used exclusively for proportioning elements of a particular construction material throughout the structure.

**2.1 GENERAL [ASCE 7 2010]**

Buildings and other structures shall be designed using the provisions of either Section 2.3 *[SD]* or 2.4 *[ASD]*. Where elements of a structure are designed by a particular material standard or specification, they shall be designed exclusively by either Section 2.3 or 2.4.

March 13, 2017 International Masonry Insititute - Hawaii 9

Codes – ASCE 7

**2012 IBC**

**2.1 GENERAL [ASCE 7 2005]**

Buildings and other structures shall be designed using the provisions of either Section 2.3 *[SD]* or 2.4 *[ASD]*. Either Section 2.3 or 2.4 shall be used exclusively for proportioning elements of a particular construction material throughout the structure.

Negative step required.

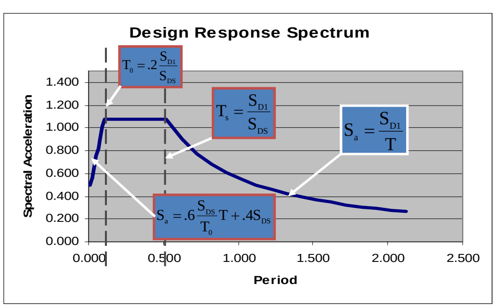
**2.1 GENERAL [ASCE 7 2010]**

Buildings and other structures shall be designed using the provisions of either Section 2.3 *[SD]* or 2.4 *[ASD]*. Where elements of a structure are designed by a particular material standard or specification, they shall be designed exclusively by either Section 2.3 or 2.4.



**Ground Motion**


Response Spectrum



Ground Motion Soil

$$S_{MS} = F_a S_s$$

$$S_{M1} = F_v S_1$$

13

Ground Motion Soil

| | Short Duration Site Modefication (Fa) | | | | |
|---|---|---|---|---|---|
| | | | Ss | | |
| Soil | 0.25 | 0.5 | 0.75 | 1 | >1.25 |
| A | 0.8 | 0.8 | 0.85 | 0.8 | 0.8 |
| B | 1 | 1 | 1 | 1 | 1 |
| C | 1.2 | 1.2 | 1.1 | 1 | 1 |
| D | 1.6 | 1.4 | 1.2 | 1.1 | 1 |
| E | 2.5 | 1.7 | 1.2 | 0.9 | 0.9 |
| F | Note b | Note b | Note b | Note b | Note b |

14

Ground Motion Soil

| | One Second Duration Site Modefication (Fv) | | | | |
|---|---|---|---|---|---|
| | | | S1 | | |
| | 0.1 | 0.2 | 0.3 | 0.4 | >.5 |
| A | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| B | 1 | 1 | 1 | 1 | 1 |
| C | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 |
| D | 2.4 | 2 | 1.8 | 1.6 | 1.5 |
| E | 3.5 | 3.2 | 2.8 | 2.4 | 2.4 |
| F | Note b | Note b | Note b | Note b | Note b |

15

Ground Motion Soil

$$S_{MS} = F_a S_s$$

$$S_{M1} = F_v S_1$$

16

Seismic Design Category Occupancy

| Select Seismic Use Group | |
|---|---|
| III | Fire, Hospital, Emergency, control towers |
| II | 300 people, eduction, jails, power stations, water treatment plan, medical facilitis |
| I | Not I and II |

| Seismic Importance Factor | |
|---|---|
| III | 1.5 |
| II | 1.25 |
| I | 1 |

17

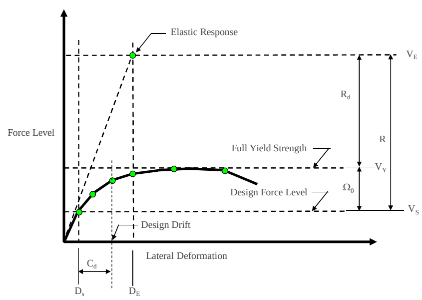
Seismic Design Category

| Design Category based Sds | | | |
|---|---|---|---|
| Sds | I | II | III |
| 0.167 | A | A | A |
| 0.33 | B | B | C |
| 0.5 | C | C | D |
| >.5 | D | D | D |

| Design Category based on Sd1 | | | |
|---|---|---|---|
| Sd1 | I | II | III |
| 0.067 | A | A | A |
| 0.133 | B | B | C |
| 0.2 | C | C | D |
| >.2 | D | D | D |

18

## Inelastic Force –Deformation Curve




19

## Base Shear – Equivalent Lateral Force Method

$$V = C_s W$$

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I_E}\right)}$$

$$C_{s(max)} = \frac{S_{D1}}{\left(\frac{R}{I_E}\right)T}$$

$$C_{s(min)} = .044 S_{DS} I_E$$

20

## Seismic Design Category Irregularities

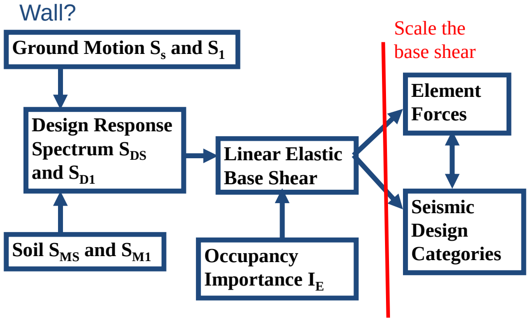
**Table 12.3-1 Horizontal Structural Irregularities**

| Type | Description | Reference Section | Seismic Design Category Application |
|---|---|---|---|
| 1a. | **Torsional Irregularity:** Torsional irregularity is defined to exist where the maximum story drift, computed including accidental torsion with $A_x = 1.0$, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drifts at the two ends of the structure. Torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid. | 12.3.3.4<br>12.7.3<br>12.8.4.3<br>12.12.1<br>Table 12.6-1<br>16.2.2 | D, E, and F<br>B, C, D, E, and F<br>C, D, E, and F<br>C, D, E, and F<br>D, E, and F<br>B, C, D, E, and F |
| 1b. | **Extreme Torsional Irregularity:** Extreme torsional irregularity is defined to exist where the maximum story drift, computed including accidental torsion with $A_x = 1.0$, at one end of the structure transverse to an axis is more than 1.4 times the average of the story drifts at the two ends of the structure. Extreme torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid. | 12.3.3.1<br>12.3.3.4<br>12.3.4.2<br>12.7.3<br>12.8.4.3<br>12.12.1<br>Table 12.6-1<br>16.2.2 | E and F<br>D<br>D<br>B, C, and D<br>C and D<br>C and D<br>D<br>B, C, and D |
| 2. | **Reentrant Corner Irregularity:** Reentrant corner irregularity is defined to exist where both plan projections of the structure beyond a reentrant corner are greater than 15% of the plan dimension of the structure in the given direction. | 12.3.3.4<br>Table 12.6-1 | D, E, and F<br>D, E, and F |
| 3. | **Diaphragm Discontinuity Irregularity:** Diaphragm discontinuity irregularity is defined to exist where there is a diaphragm with an abrupt discontinuity or variation in stiffness, including one having a cutout or open area greater than 50% of the gross enclosed diaphragm area, or a change in effective diaphragm stiffness of more than 50% from one story to the next. | 12.3.3.4<br>Table 12.6-1 | D, E, and F<br>D, E, and F |
| 4. | **Out-of-Plane Offset Irregularity:** Out-of-plane offset irregularity is defined to exist where there is a discontinuity in a lateral force-resistance path, such as an out-of-plane offset of at least one of the vertical elements. | 12.3.3.3<br>12.3.3.4<br>12.7.3<br>Table 12.6-1<br>16.2.2 | B, C, D, E, and F<br>D, E, and F<br>B, C, D, E, and F<br>D, E, and F<br>B, C, D, E, and F |
| 5. | **Nonparallel System Irregularity:** Nonparallel system irregularity is defined to exist where vertical lateral force-resisting elements are not parallel to the major orthogonal axes of the seismic force-resisting system. | 12.5.3<br>12.7.3<br>Table 12.6-1<br>16.2.2 | C, D, E, and F<br>B, C, D, E, and F<br>D, E, and F<br>B, C, D, E, and F |

21

Codes

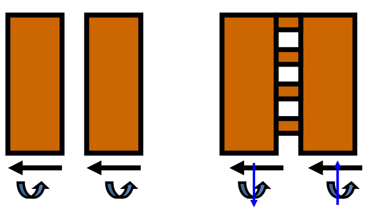
## How Do I Find the Seismic Load in a Masonry Wall?






Distribution of Loads

- Computer analysis normal today






Design of Elements

- Load combinations, strength design (IBC 2012)

| | |
|---|---|
| **1.2D + .5L + E** | **Formula 16-5** |
| **.9D + E** | **Formula 16-6** |
| **$E = \rho Q_E + .2S_{DS}D$** | **Equation 12.4-5 [ASCE 7]** |
| **$E = \rho Q_E - .2S_{DS}D$** | **Equation 12.4-6 [ASCE 7]** |

## Design of Elements

- Load combinations, allowable stress design (IBC 2012)

| | |
|---|---|
| **D + L + S + .7*E** | **Formula 16-10** |
| **.6D + .7*E** | **Formula 16-12** |
| **$E = \rho Q_E + .2S_{DS}D$** | **Equation 12.4-5 [ASCE 7]** |
| **$E = \rho Q_E - .2S_{DS}D$** | **Equation 12.4-6 [ASCE 7]** |



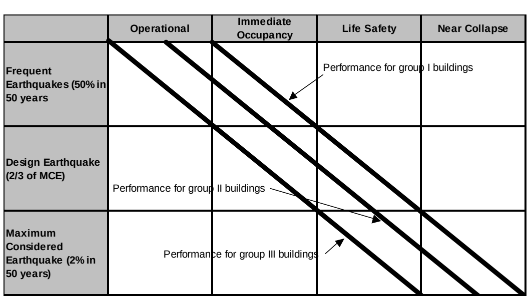
## Design of Elements

- Load combinations, alternative allowable stress design (IBC 2012)

| | |
|---|---|
| **D + L + S + E/1.4** | **Formula 16-17** |
| **.9D + E/1.4** | **Formula 16-18** |
| **$E = \rho Q_E + .2S_{DS}D$** | **Equation 12.4-5 [ASCE 7]** |
| **$E = \rho Q_E - .2S_{DS}D$** | **Equation 12.4-6 [ASCE 7]** |



## Codes



## Codes

| | Operational Level | Immediate Occupancy Level | Life Safety Level | Collapse Prevention Level |
|---|---|---|---|---|
| **Overall Damage** | Very Light | Light | Moderate | Severe |
| **Personnel Safety** | No injuries | Minor injuries | Minor injuries | Major injuries or deaths |
| **Structural Frame** | Minor or no damage to the structural frame. Since repair is not required, operations are not interrupted | Minor, repairable damage to structural frame. Does not interfere with immediate use, but may interfere with long-term use | Structural frame is permanently damaged and may not be repairable | Structural Frame is near collapse |
| **Cladding** | Little or no cladding damage. Operations not interrupted for repair. | Minor cladding damage. Does not interfere with immediate operations, but may require future repair or replacement. | Damage to cladding but cladding remains on the building. Cladding may have to be replaced. | Extensive loss of cladding |
| **Windows** | No window damage | Minor or no window damage | A few windows may be broken | Extensive broken windows |
| **Doors** | No jamming of doors. | Some doors jammed. Requires immediate repair. | Some doors jammed. No exits blocked. | Extensive jamming of doors and blocking of exits. |
| **Walls** | Little or no damage to walls. Operations not interrupted for repair. | Minor damage of walls. Requires repair in the future | Extensive damage of walls, many not repairable. | Extensive damage of walls, many not repairable. |

March 13, 2017 International Masonry Institute - Hawaii 28

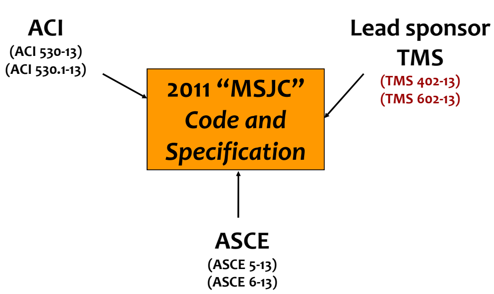
## Codes

| | Operational Level | Immediate Occupancy Level | Life Safety Level | Collapse Prevention Level |
|---|---|---|---|---|
| **Mechanical and Electrical Systems** | No damage to mechanical and electrical systems. Operations continue uninterrupted. Power and utilities are available form auxiliary sources. | Minor damage of mechanical and electrical systems. Repairable in 24 hours or less if repair services are available. Power and utilities may be unavailable. | Moderate damage of mechanical and electrical systems. May not be repairable. | Extensive damage of mechanical and electrical systems, not repairable. |
| **Elevators** | Elevators functional. | Moderate damage of elevators. May not be functional for several days, if repair services are available. | Extensive damage of elevators, may be repairable. | Extensive damage or elevators, not repairable |
| **Computers and Data Storage** | Fully functional. No loss of data. | Minor damage, requiring repairs. Data may be lost. Down time depends on availability of repair services. | Extensive damage, may be repairable. | Extensive damage, not repairable |
| **Sensitive Equipment** | No damage to sensitive equipment. | Moderate damage, requiring repairs. Experiments lost. Down time depends on availability of parts and repair services. | Extensive damage, not repairable | Extensive damage, not repairable. |

March 13, 2017 International Masonry Institute - Hawaii 29

## Codes

2016 and beyond editions will be produced solely by TMS. As such, we'll use TMS 402/602




March 13, 2017 International Masonry Insititute - Hawaii 30

## Codes

Code and Specification

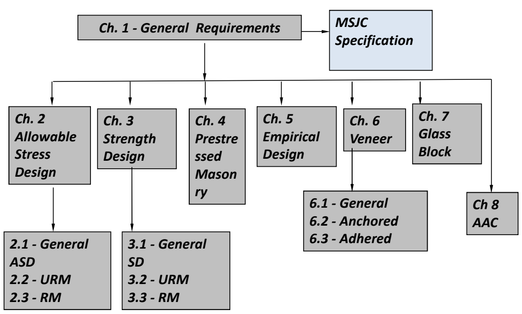
TMS 402 “Code”
- Design provisions
- QA program in accordance with the Specification
- Section 1.4 invokes the Specification by reference.

TMS 602 “Specification”
- Verify compliance with specified $f'_m$
- Comply with specified products and execution
- Comply with required level of quality assurance



## Codes

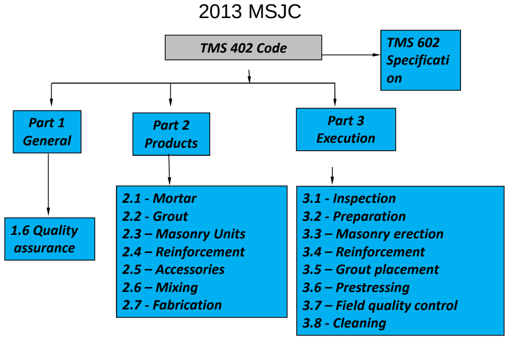
2011 MSJC






## Codes

2013 MSJC



## Codes – TMS 602 – 13 specification

**Table 2 — Compressive strength of masonry based on the compressive strength of concrete masonry units and type of mortar used in construction**

| Net area compressive strength of concrete masonry, psi (MPa) | Net area compressive strength of concrete masonry units, psi (MPa) | |
|---|---|---|
| | Type M or S mortar | Type N mortar |
| 1,700 (11.72) | --- | 1,900 (13.10) |
| 1,900 (13.10) | 1,900 (13.10) | 2,350 (14.82) |
| 2,000 (13.79) | 2,000 (13.79) | 2,650 (18.27) |
| 2,250 (15.51) | 2,600 (17.93) | 3,400 (23.44) |
| 2,500 (17.24) | 3,250 (22.41) | 4,350 (28.96) |
| 2,750 (18.96) | 3,900 (26.89) | ----- |
| 3,000 (20.69) | 4,500 (31.03) | ----- |

[1]For units of less than 4 in. (102 mm) nominal height, use 85 percent of the values listed.

Revised values for compressive strength of masonry Concrete masonry units of 2000 psi in type M or S mortar have a compressive strength of 2000 psi



## Codes – TMS 602 – 13 specification

Starting with the 2008 MSJC code/specification, self-consolidating grout is permitted

- SCG penetrates voids and surrounds reinforcement without requiring mechanical vibration for consolidation.



## Codes – and the Structural Engineers Negligence

| | No Failure | Failure |
|---|---|---|
| Satisfies the Code | Not Negligent | Negligent |
| Does not Satisfy the Code | Negligent | Negligent |