

**WSCP A SUMMIT**

**on**

**Rho Max**

**March 3, 2002**

**Marina Del Rey  
Los Angeles  
California**

**Contents**

**Executive Summary**

**Introduction**

**The Summit**

**Purpose and Objectives**

**Results Trial Designs**

**Results Discussion Charts**

**Results Issues Found**

**Appendix**

**Example Solutions**

**Transcript**

## **Executive Summary:**

The drafters of the reinforcement limitation provisions (Rho Max.) in the 2002 Building Code Requirements for Masonry Structures and the 2000 International Building Code did not understand the impact these provisions would have on the design of load bearing masonry buildings. To demonstrate the impact, a summit meeting was organized and conducted on March 2, 2002. Six of the eleven attendees prepared trial designs of two masonry walls. The walls were taken from the Masonry Designers Guide RJC Hotel with two stories added, making it a 6-story building.

In general the six trial solutions resulted in the same design. The design of one wall was a 12-inch CMU with a design strength of 2000 psi. The other wall (with two openings) could not be designed in masonry. It was clear to all attendees that the Rho Max limitation results in unacceptable designs. All the design engineers at the summit indicated that they would not design similar buildings in masonry. They would select another material such as concrete.

There was general agreement that the Rho Max provisions are too restrictive and needed revision. Most believed that the major problem with the Rho Max provision is the criteria to prevent toe crushing of walls. The provision addresses only single walls within the building rather than addressing the entire building system. Recommendations or solutions were not forthcoming and the group suggested another meeting and more research.

In the months following to the meeting several changes to the Rho Max provisions have been proposed. They are somewhat less restrictive but continue to embrace the concept of toe crushing prevention as the driving performance criteria.

## Introduction:

The new codes contain provisions severely restricting the use of masonry in many common applications. One particularly restrictive provision limits the reinforcement in masonry walls. The common term to describe the provision is "Rho Max". "Rho" means the percentage of reinforcement in the wall (area of steel divided by the area of masonry). "Max" means there are maximum amounts allowed by the code.

For those not following the development of the structural codes, a maximum amount of reinforcement might seem like a benefit. For years most of the industry resisted reinforcing masonry. And, when it was reinforced, it was always too much steel or over designed. Some might think that a limit could be a benefit in the end. Not true.

The real consequence of Rho Max is to limit the amount of compression load on a wall, not the reinforcement. In other words, the primary asset of the masonry material, its compression capacity, is now severely limited. A six story typical residential building with load bearing walls requires 12 CMU with a design strength of 2000 psi. This design will not be competitive with other material systems such as concrete and therefore masonry is effectively eliminated from consideration.

The Rho Max provisions governing maximum flexural reinforcement were originally developed for the 1997 NEHRP document. Their intent is to ensure ductile behavior in flexure. They differ considerably from previous maximum reinforcement provisions in several respects:

- “
- 1. They address the effect of axial load on the mode of flexural failure.*
  - 2. They address differences in inelastic deformation requirements between elements loaded in-plane, and elements loaded out-of-plane.*
  - 3. The old “50%  $\rho_b$ ” requirement could, under some levels of axial load, lead to brittle flexural failures. The new requirements are intended to prevent this, and to impose maximum reinforcement limits in a more rational way.”<sup>1</sup>*

The drafters of the 2002 Building Code Requirements for Masonry Structures and the 2000 International Building Code adopted the NEHRP provisions without understanding the impact these provisions would have on the design of load bearing masonry buildings. Objections were raised, but overruled. The provisions made it into the regulations without testing their impact on actual design and construction.

To demonstrate the impact, WSPCA sponsored a summit meeting of the principal players in the development of the Rho Max limitations. The summit was conducted on March 3, 2002. Six of the eleven attendees prepared trial designs of two masonry walls. The walls were taken from the Masonry Designers Guide RJC Hotel with two stories added, making it a 6-story building.

## The Summit and Results:

The purpose of the summit was to explore and record the effects of the maximum reinforcement provisions of the 2002 MSJC Code on the design and construction of load bearing masonry buildings. The summit was held in Los Angeles on March 1 and 2, 2002 at the Marina Del Rey Hotel. Those attending were:

Dan Abrams, University of Illinois  
Russ Brown, Clemson University  
John Chrysler, WSCPA  
Steve Dill, KPF  
Jeff Elder, WSCPA  
Ed Huston, Smith & Huston Inc.  
Eric Johnson, BIA  
Mike Kanonik, David Biggs and Associates  
Rich Klinger, University of Texas, Austin  
John Tawresey, KPF  
Jason Thomson, NCMA  
Terry Weigel, University of Louisville

### The objectives were:

1. To record and document the opinions of the promoters of the Rho Max provision.

The attached transcript to the proceedings provides the record.

2. To define the performance criteria of the provisions. Are they intended to for life safety or damage control?

There was general agreement that the performance criteria have not been specified.

Transcript Page 2, line 31:

*MR. THOMPSON: If you look at how we want buildings to perform as a system instead of as elements. Terry had kind of broached the subject. Are we looking only at life safety? Do we want those systems to perform at a given level, and then what provisions give us that level of performance as opposed to giving us a prescriptive requirement. The prescriptive requirement gives us a level that is not explicitly stated. What level is it?*

*MR. TAWRESEY: So there is a range of performances. We are just looking at one level right now.*

*MR. THOMPSON: And I don't know if that one level we are all in agreement with.*

*MR. KLINGNER: It's a level but what is that level?*

3. To define the relationship between strength and ductility. Is there a trade-off?

The concept was recognized but no proposals were forthcoming.

*MR. DILL: .....It's everywhere and I think we are getting trapped.*

*You started out by saying that we want those piers to be ductile. I'm not sure we do. I'm not sure we want those piers to be ductile. We may want them to be strong.*

*MR. KLINGNER: That's a good -- good intentions driving us toward a design for that entire wall system.*

4. To see if designers get different answers when applying the provisions to the same problem.

The solutions were generally the same.

*MR. BROWN: Sure. My reaction is that I'm surprised we should have such close agreement in designs. I think the solutions were more or less all correct. There are three or four issues that we are not in complete agreement on, and I think we have written them down on the carts.*

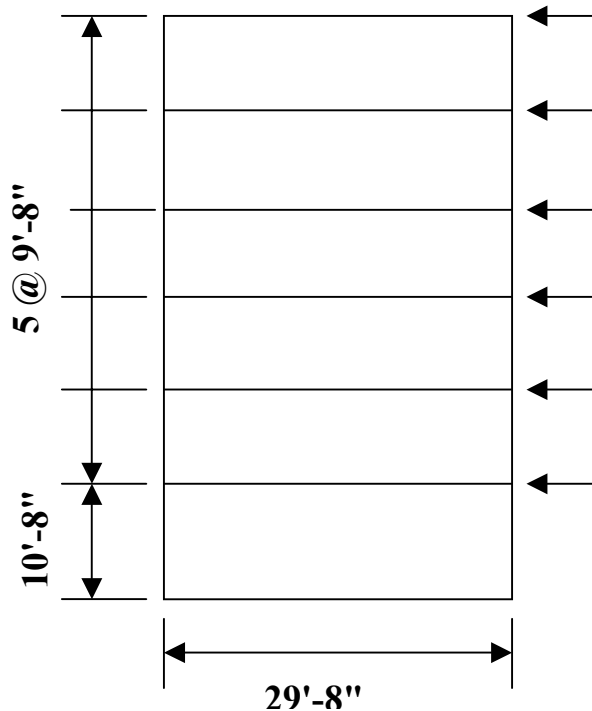
### The Summit Results - Trial Design

The following presents the trial designs and summarizes the solution in tabular form. Detailed solutions based on the information learned from the summit are contained in the appendix.

#### Trial Design Number 1

This problem was taken from the Masonry Designers Guide RJC Hotel. It is the wall on grid line C between 1 and 2. Two floors were added and a new lateral force analysis conducted to determine appropriate lateral loads.

Design the wall by determining the wall thickness and reinforcement required. Prepare the design so that it can be used as an educational tool. Computer programs can be used, but provide equations and numbers so that anyone can substitute to reproduce the numbers. Provide notation when appropriate to assist the reader.



**Wall at grid line C  
between 1 and 2**

Cumulative Loads (Top of Wall)				
Floor No.	Shear (E) Kip	Moment (E) Kip-Ft	Dead Load Kip/Ft	Live Load Kip/Ft
R	39.0	0	2.85	.6
6	99.2	377	6.83	1.32
5	145.1	1336	10.8	1.81
4	176.5	2739	14.8	2.24
3	177.2	4446	18.8	2.67
2	252.3	6160	22.75	3.10
1	252.3	8893	23.5	3.10

1. Assumes wall weight of 70 psf.
2. Includes live load reduction.

The wall is single wythe CMU masonry with the following material properties:

$f'_m = 1500$  psi, 2000 psi (special order), 3000 psi (special order from Seattle)

$F_y = 60,000$  psi (Grade 60)

Units \_\_\_x8x16 available in 6,8,10 and 12 inch nominal thickness

Design for the following loading conditions:

1.  $.9D + E$
2.  $1.2 D + .5 L + E$

Design for both axial load with compression and shear. Use the most recent MSJC Code (copy included).

The building is an IBC 2000 Seismic Design Category C. The required minimum reinforcement is .002 in both directions and .0007 in any one direction.

**Solutions:**

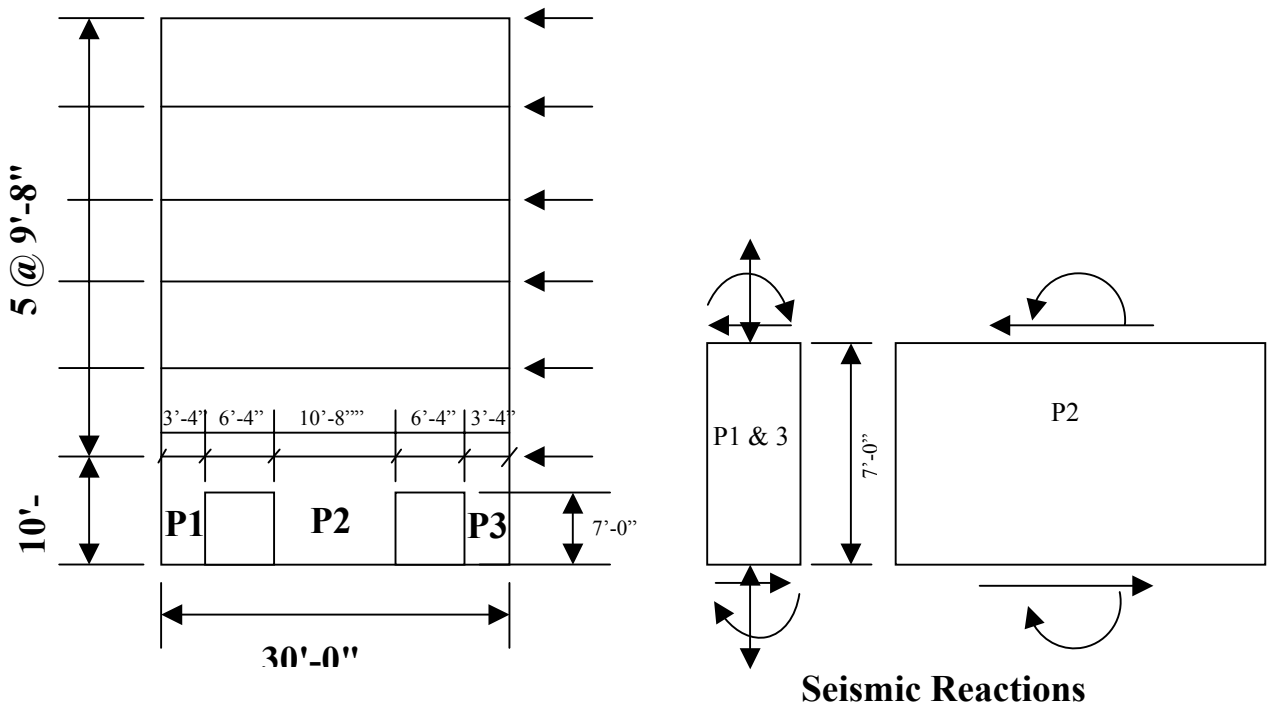
The following table summarizes the solutions to trial design 1:

Solution No.	WALL THICKNESS	MASONRY STRENGTH	REINFORCE-MENT
1	12"	2000	#4@24
2	12"	3000	#6@16
3	12"	2000	(8) #6 (at ends of the wall)
4	NO SOLUTION	N/A	N/A
5	8"	3000	(8)#5
	12"	2000	(8)#6
6	8"	3000	#4@24
	12"	2000	#4@24

**Trial Design Number 2**

This problem was taken from the Masonry Designers Guide RJC Hotel. It is the wall on grid line C between 3 and 4. Two floors were added and a new lateral force analysis conducted to determine appropriate lateral loads.

Design piers 1 and 2 by determining the wall thickness and reinforcement required. Prepare the design so that it can be used as an educational tool. Computer programs can be used, but provide equations and numbers so that anyone can substitute to reproduce the numbers. Provide notation when appropriate to assist the clear reader.



**Wall at grid line C  
between 1 and 2**

Pier Loads (signs as shown in figure)						
Pier No.	Location	Seismic Loads			Dead Load Kip (Revised 2/19/02)	Live Load Kip (Revised 2/19/02)
		Shear Kip	Moment Kip-Ft	Axial Kip		
P1 & 3	Top	4.5	4.2	±181.4	149.5	20.2
	Bottom	4.5	27.3	±181.4	151.1	20.2
P2	Top	63.8	255.8	0	391.0	52.7
	Bottom	63.8	702.4	0	396.2	52.7

1. Assumes wall weight of 70 psf.
2. Includes live load reduction.

The wall is single wythe CMU masonry with the following material properties:

$f'_m = 1500 \text{ psi}, 2000 \text{ psi (special order), } 3000 \text{ psi (special order from Seattle)}$   
 $F_y = 60,000 \text{ psi (Grade 60)}$   
 Units   x8x16 available in 6,8,10 and 12 inch nominal thickness

Design for the following loading conditions:

$$.9D + E$$

$$1.2 D + .5 L + E$$

Design for both axial load with compression and shear. Use the most recent MSJC Code (copy included).

The building is an IBC 2000 Seismic Design Category C. The required minimum reinforcement is .002 in both directions and .0007 in any one direction.

**Results:**

The following table summarizes the solutions to trial design 2:

PIER 1 & 3

Solution No.	WALL THICKNESS	MASONRY STRENGTH	REINFORCE-MENT
1	12"	3600	(3)#6
2	NO SOLUTION	N/A	N/A
3	NO SOLUTION	N/A	N/A
4	NO SOLUTION	N/A	N/A
5	NO SOLUTION	N/A	N/A
6	20"	3000	#4@5"

PIER 2

Solution No.	WALL THICKNESS	MASONRY STRENGTH	REINFORCE-MENT
1	12"	3000	#4@24
2	NO SOLUTION	N/A	N/A
3	12"	3000	(4)#5
4	12"	3000	N/A
5	12"	3000	(4)#5
6	12"	3000	6@#4

## The Summit Results – Discussion Charts

The following information was placed on charts during the discussion of the trial designs and subsequent deliberations. The transcript of the deliberations is contained in the appendix.

1. Should the  $\rho_{\max}$  calculation include the stresses in the compression reinforcement even though MSJC does not allow the stresses to be included in calculation of resistance unless the bars are tied.

*Most agreed that the MSJC does allow the compression reinforcement stress to be included.*

*All agreed that it should allow compression reinforcement stresses to be included.*

2. The IBC allows compression reinforcement stresses to be used in calculating resistance even when not tied. The MSJC does not.

*The code writers will resolve this. Most (all?) agreed that compression reinforcement should be used.*

3. Is a shear failure of wall P2 critical?

*It could be but it depends on the design of the remainder of the building. A discussion of system resistance versus element resistance provided no resolution.*

4. In the provision for designing shear at a level consistent with  $1.25 M_u$  contained in section 3.1.3 of the MSJC, what value of  $M_u$  should be used?

*Clarification of the provision:*

*A ratio of the actual moment in the section to 125% of the flexural strength of the section should be computed,  $(M_u / 1.25 M_n)$ . This ratio should be used to factor the shear associated with  $M_u$  (i.e.  $V_u$ ). The factor should be  $\leq 2.5$ . This factored shear should be compared to the shear strength of the section.*

5.  $\rho_{\max}$  does not apply to P1 and P2 because they are piers and MSJC section 3.2.3.5.1 (a) does not include piers.

*All accepted the code provided an out from  $\rho_{\max}$  except for one who believed it was unclear. All agreed that the intent was for the  $\rho_{\max}$  provision to apply to piers. The ductility required by the pier in the examples has more to do with*

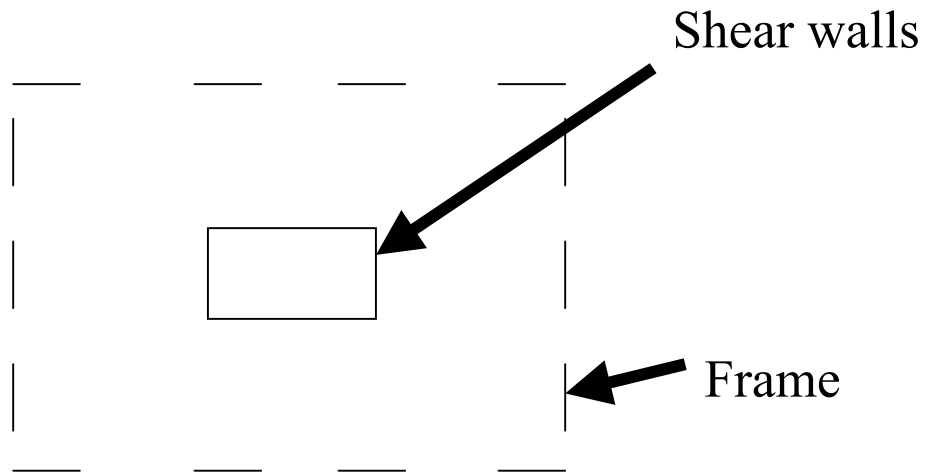
*tension and compression than with flexure, another discussion of system ductility relative to flexural ductility ensued.*

6. The MSJC does not specifically address the reduction in shear allowable for elements that contain net tension due to seismic overturning.

*All agreed the code was OK as it is. Some felt that tension should be considered as negative compression when using the formula for shear strength in the masonry ( $V_m$ ).*

7. The 80% wall stiffness requirement of MSJC section 3.1.3.1 eliminates combined frame and shear wall building types allowed in other material systems.

Figure 1 Shear Wall and Frame System



*MSJC will review this restriction. The implications of the provision may not have been fully understood when originally written. Interpretation of the 80% stiffness is also unclear.*

8. What is the definition of "d". MSJC defines the d as the distance from the extreme compression fiber to the centroid of the reinforcement. This is not consistent with published equations for  $\rho_{max}$ .

*The full length of the wall should be used when calculating  $\rho_{max}$ .*

9. Does the 6 story RCJ hotel work with the  $R = 1.5$  option available?

*This was intended as the elastic response. But  $n = 2$  was still required and therefore requires considerable ductility. Discussion concluded that  $n$  should be a function of the system  $C_d$  instead of the system  $R$ . Actual inelastic drift demand will be a function of  $C_d$  times elastic drift. For a specific building, these may be*

*substantially less than those used to develop the current flexural ductility provisions.*

*If  $R = 1.5$  is  $\rho_{max}$  necessary. Consensus was no, but a possible over-strength factor might be required.*

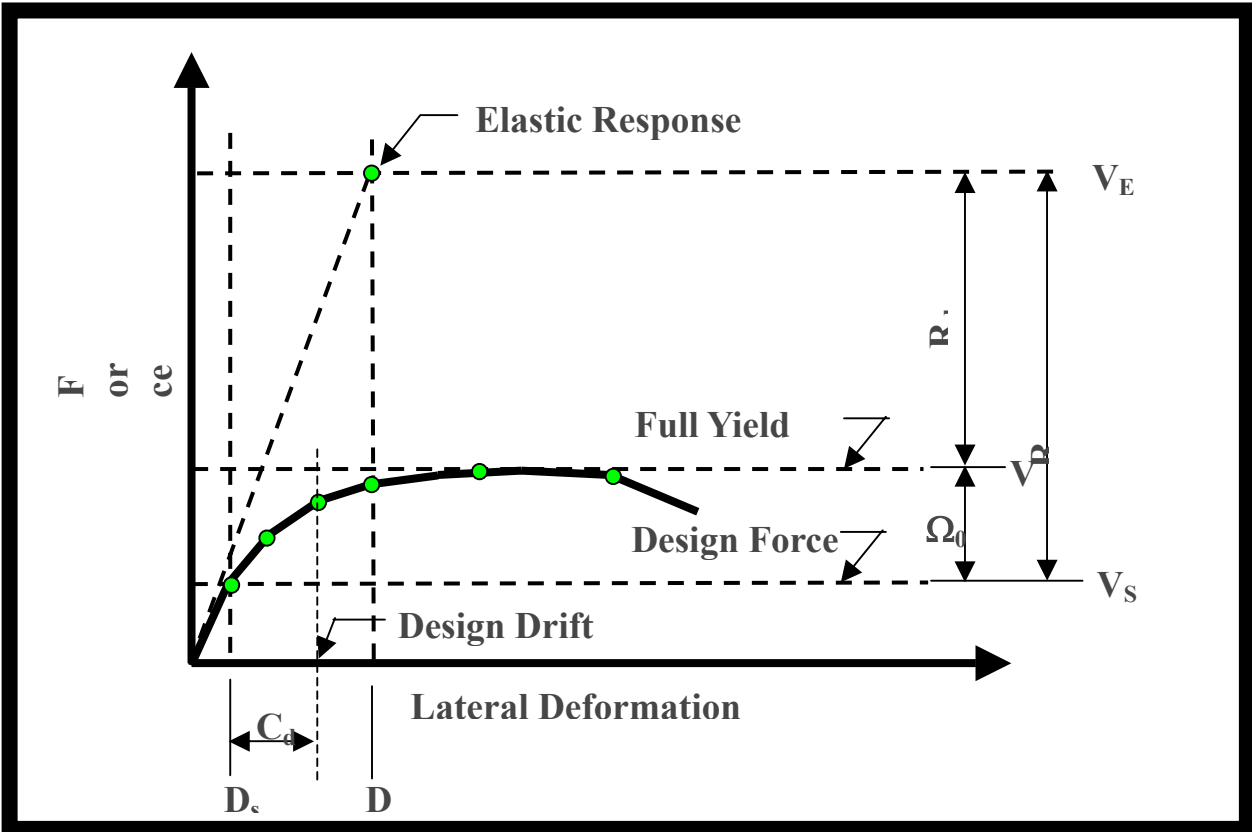


Figure 2 Representation of the System Force Displacement Diagram

10. The criteria for establishment of  $\rho_{max}$  should be reviewed. The criterion is now based on drift and perhaps should consider ductility.

*Discussion was combined with item 9.*

11. What is the correct method for calculation of  $\rho_{max}$ . Should it include compression stresses in reinforcement? Should it have the Dill plateau?

*The discussion was integrated into other items and the design examples. It was generally agreed that the compression reinforcement stress should be included in order to prevent  $\rho_{max}$  from being more restrictive on design.*

12. The  $\rho_{max}$  provision favors concentrated reinforcement.

*It was agreed that this was the effect of the provision. Most designers assumed distributed steel and ended up with thicker walls. The 10" solution for the first design example used concentrated reinforcement.*

13. The  $\rho_{\max}$  provision will encourage a market for low yield strength steel and negative steel.

*Comic relief for a long day.*

14. Should the axial load in the  $\rho_{\max}$  provision include the effect of seismic overturning compression forces.

*Some concluded that it should not. The group felt that the provision should be more related to the system requirements than the local elements. Inclusion of the axial load due to overturning would make the  $\rho_{\max}$  provision even more restrictive.*

15. Is tension rupture of reinforcement a problem with the low amounts of reinforcement required by the  $\rho_{\max}$  provision.

*The out-of-plane provisions require sufficient reinforcement to prevent the problem. It is not required in-plane. MSJC recognized this and did not include in-plane provisions because they depend on bar size and gauge length. More study is required.*

16. Is a shear failure OK?

*No resolution on this question.*

### The Summit Results – Issues Found

The following chart lists the issues requiring some action or decision. They were identified during the summit and subsequent deliberations.

#### Issues for Consideration

Item	Issue	Transcript Reference	Action Recommended
1	MSJC Section 3.2.3.5.2 (n=2) was intended to apply only to in-plane loading of walls. As written it also applies to out-of-plane loading. It is in conflict with the n of 1.3 of previous provisions.	P33-L41	Change the code this cycle.
2	Does Rho Max apply to piers? Current language is not clear.	P5-L38, P19-L27, P19-L27	Change the code this cycle.
3	Does Rho Max apply to all elements of a building or only those that participate in the seismic resistance?	P5-L25, P20-L19	Address the issue during this code cycle. The code should be clarified that Rho Max applies to piers.
4	Should compression forces in the reinforcement be included in the calculation of Rho Max, and should the "Dill Plateau" be allowed?	P1-L23, P9-L45, P13-L29, P15-L27	Address the issue during this code cycle. The code should say "include compression steel force"
5	Should compression forces in the reinforcement be included in the capacity calculation of elements even if the compression reinforcement is not tied?	P12-L9, P16-L24	Address the issue during this code cycle. The code should allow the inclusion of compression reinforcement force without being tied.
6	Rho Max addresses the ductility of elements. But seismic design is based on the ductility of the system. Do the provisions of the seismic loading chapters adequately address the issue without the addition of Rho Max? Or, is it necessary for masonry to add the Rho Max requirement.	P7-L36, P18-L38, P23-L44	Continued discussion. Resolution is complex and not totally within the control of the masonry code process.

Item	Issue	Transcript Reference	Action Recommended
7	Rho Max develops flexural ductility. For many geometries and building configurations it is not possible to create the flexural hinge. The long warehouse wall is an example of a shear critical element. The piers in trial design 2 are examples of tension and compression critical elements.	P1-L35, P20-L30	Continued discussion. Resolution is complex and not totally within the control of the masonry code process.
8	If a designer uses an R of 1.5, should the designer be able to escape Rho Max if there are appropriate over strength factors? Should R and the n factor be related?	P34-L15, P35-L31, P36-L44, P39-L2	Address this code cycle. Code should wave Rho Max for reinforced walls when the designer uses an R of 1.5.
9	Section 3.1.3.1 requiring 80% of the lateral stiffness be provided by walls is redundant to the building stiffness irregularity provisions contained in the seismic loading sections of the code. Is the section necessary?	P18-L38, P30-L5	Address this issue during this code cycle.
10	The Rho Max procedures encourage lumped (trim) reinforcement at the ends of the walls. Is this OK?	P5-L25, P41-L1	Address this issue in this code cycle.
11	The Rho Max procedures encourage the use of low yield reinforcement in load bearing walls. Is this OK?	P5-L25	Address this issue in this code cycle.
12	The provisions for out-of-plane ductility never control. Why are they in the code?	P1-L41	Address this issue in this code cycle.
13	Rho Max produces designs that are not acceptable to professional engineers or owners. The designs are not competitive with other material systems or consistent with the existing standards and experience with masonry load bearing buildings	P4-L7, P4-L42, P5-L19, P7-L8, P7-L31, P9-L4, P44-L43, P48-L33	Continued discussion. Resolution is complex and not totally within the control of the masonry code process.
14	Is it necessary to prevent toe crush for masonry buildings? Does limiting toe crush increase the chance of tension steel rupture?	P1-L19, P1-L33, P7-L18, P7-L25, P11-L31, P42-L37, P47-L21	Continued discussion. Resolution is complex and not totally within the control of the masonry code process.

Item	Issue	Transcript Reference	Action Recommended
15	The expected building performance with Rho Max is not defined.	P1-L12, P2-L31, P35-L18	Address this code cycle.
16	Strength design is more conservative than allowable stress design, which is more conservative than empirical design. This seems backward.	P3-L18, P5-L4	Continued discussion. Resolution is complex and not totally within the control of the masonry code process.
17	What is "d"?	P4-L2, P31-L13	Address this issue this code cycle.
18	Design for flexure requires only a check of capacity against the given loads. Unlike the 2000 IBC, the 2002 MSJC has no requirement that the nominal flexural strength be at least 1.5 times the cracking moment.	Example problem discussion not recorded	Address this issue this code cycle.
19	In the Rho Max equation the value of axial load is unfactored in the MSJC but factored in the IBC 2000.	Recognized when reviewing hard copy of the trial designs.	Address this issue this code cycle.