Meeting Summary

The 27 February 2010 Chile Earthquake: Implications for U.S. Building Codes and Standards

Organized by

American Society of Civil Engineers,
National Institute of Standards and Technology, and
Pacific Earthquake Engineering Research Center

Hosted by Simpson Gumpertz & Heger.

Meeting Time:	10 AM -5 PM Pacific Time Wednesday, 2 June 2010
Meeting Location:	Conference Room Simpson Gumpertz & Heger, 1 Market Street, 6th Floor San Francisco, CA
Attendees:	See Appendix A

10:00 AM **1. Welcome and Introductions**

Moehle and Hayes opened meeting, and welcomed participants. Participants introduced themselves and noting their affiliation with official U.S. teams or Chilean groups that carried out reconnaissance following the M_w 8.8 earthquake that occurred in Chile on 27 February 2010. Several participants joined via telephone and WebEx. See Appendix A.

10:10 AM **2. Meeting objectives and agenda**

Hayes gave a brief overview of the purpose of the meeting (Appendix B). He indicated that this would likely be the first of several meetings in the US related to the earthquake engineering implications of the 27 February 2010 Chilean earthquake. In this regard, Moehle indicated that EERI is being funded by NSF to convene a moderate-sized workshop later in 2010 to identify and prioritize research needs arising from the recent Chilean earthquake.

Moehle recapped the agenda (Appendix C) and thanked participants for submitting forms describing topics for potential investigation. Hayes and Moehle encouraged full discussion of all these ideas by all participants.

10:20 AM **3. Brief opening comments by Chilean participants**

The Chilean participants going in person or via WebEx offered comments about the situation in Chile and the desirability of US-Chilean investigations related to the recent earthquake. All were appreciative of being included in the meeting. The primary form of construction that is of concern to Chilean engineers is cast-in-place reinforced concrete buildings, often tall with structural walls, but also includes lower rise concrete buildings with masonry infills and precast concrete construction.

Saavedra indicated that practicing engineers in Chile have many questions about the causes of the observed damage. Chilean engineers are in the process of designing many new buildings and repairing and retrofitting many more. An improved understanding of structural behavior and the adequacy of current code provisions being used in these efforts is urgently needed. He looked forward to working with researchers and practitioners in the US to help identify improvements in design methods.

Lagos indicated that Chilean designers follow ACI 318 (with some Chilean exceptions), but some detailing practices (e.g., numerous thin and relatively lightly reinforced structural walls) differ from US practice. Some of buildings that appear to be designed and detailed consistent with the current Chilean code provisions did not behave as expected and were extensively damaged.

Bonelli indicated willingness on the part of Chilean engineers and researchers to provide assistance to US investigators, and that Chilean engineers would like to participate closely with US investigators involved with studying the effects of the Chilean earthquake.

De la Llera indicated that both short and long term solutions are needed. That is, there are items that need to be addressed immediately (to assess and improve repair and retrofit requirements, and provide assistance to engineering with new buildings currently in construction or in design that may have details similar to ones that were damaged). De la Llera noted however that there were also longer term needs to discuss more fundamental changes that might be needed in design code provisions and engineering practices.

10:40 AM **4. Reconnaissance summaries by EERI LFE and ASCE teams**

Wallace and Hooper gave brief presentations on behalf of the EERI Learning from Earthquakes (LFE) and ASCE reconnaissance teams. They discussed where the teams went, what buildings were visited, and the principal observations/questions that arose from the reconnaissance related to building codes. Many participants contributed additional information and posed questions during the discussions that helped in providing an overview of the damages observed.

Wallace (EERI LFE) expressed appreciation for the help provided by Chilean practicing engineers and university researchers before, during and following the reconnaissance missions. This was reiterated by all of the US teams that visited Chile.

Wallace discussed a number of topics, including:

a. Ground shaking

    i. The University of Chile operates a strong motion instrumentation array that recorded motions at several sites throughout the heavily shaken region. Several buildings are instrumented. Paper copies of accelerogram time histories and response spectra are available, but digital recordings are not yet available. Discussions by participants indicate that records may become available quite soon. While some strong motion instruments are digital, many recordings were apparently made using analog instruments.

    ii. A special characteristic of the records is the very long duration of strong shaking (90 seconds or more).

    iii. Spectral displacement demands at periods beyond 1 second appear from available data to be smaller at many sites than would be expected in the US.

b. Sites visited by EERI LFE team

i. Santiago: Not too much time spent here, as other teams were there

ii. Concepción (and San Pedro): looked at 11+ modern buildings

iii. Viña del Mar: looked at 11 red tagged buildings, plus 4+ more

c. Discussion Topics and Questions Identified

i. Degree of axial stress in structural walls – Chilean buildings are characterized by numerous structural walls, and this fact contributed to their comparatively good behavior during the 1985 earthquake. Newer buildings appear to have nearly as many walls (as a percentage of the total floor area), but buildings are now much taller on average. This suggests that the axial stress in the walls in newer buildings is much higher (perhaps more than double) than before. This may account for the widespread observation of localized wall damage characterized by buckling of vertical reinforcement. As the buildings appear to be designed consistent with current Chilean and US code provisions, the adequacy of current code provisions under higher axial stresses should be examined.

ii. Wall boundary element detailing – Exceptions are provided in the Chilean building code relative to ACI 318 that eliminate transverse reinforcement in boundary elements. Considerable damage was observed in many boundary elements, including crushing of concrete cores, and buckling and fracture of longitudinal reinforcement. Implications for the US include for *special* walls (1) whether the trigger for requiring *special* boundary elements should be based on Maximum Considered Earthquake (MCE) displacements rather than those at the Design Basis Earthquake (DBE) level, and (2) should a minimum amount of transverse reinforcement be provided at wall boundaries (and if so, when)? For buildings in the US that are designed having *ordinary* RC walls, damage under MCE and perhaps DBE may resemble that observed in Chile. The safety and re-occupancy issues created by this type of damage may warrant reconsideration of the acceptable behavior of such buildings, and modification of minimum detailing requirements. Detailed case studies are recommended for a statistically meaningful number of damaged and undamaged buildings having special and ordinary wall details.

iii. Wall vertical reinforcement – Many damaged walls were lightly reinforced and had unconfined lap splices. These walls were observed to have problems at lap splices or to suffer tension failures (or fractures during buckling following tensile elongation). Due to the long duration of the earthquake, the walls likely underwent a large number of cycles of loading. The possibility of a failure mode consisting of progressive concrete crushing and buckling or fracture of reinforcement across entire wall (unzipping) should be investigated.

iv. Configuration issues – US (but not Chilean) codes contain special provisions that are triggered by building irregularities in plan or elevation views. There are numerous damaged buildings in Chile having significant irregularities. The O'Higgins building is an example of a building having both horizontal and vertical irregularities. Many examples of vertical setback were observed (narrowing of walls near base) resulting in what many call a "flag wall" configuration[1]. Some buildings are able to redistribute loads to other elements following failure of one or more critical members. Study of code provisions related to building irregularities is desirable.

v. Building Collapse I – One 15-story reinforced concrete shear wall building in Concepción completely collapsed, and its structural system appears to have a number of significant

[1] The term "flag wall" is used commonly in Chile to describe a structural wall that has more or less uniform width over its height, except at its base. To provide greater architectural flexibility at the base, a portion of the wall on one end (or both ends) is removed. This reduction in plan dimension gives the wall the appearance of a flag on a pole.

discontinuities and irregularities. To assess our ability to model and predict collapse of structures and the adequacy of evaluation guidelines, it is highly desirable to simulate and evaluate the likely performance of this building.

vi. Building Collapse II – A significant number of buildings suffered substantial structural damage and might be considered close to collapse. It is believed that several of these, if analyzed using current guidelines for evaluation of existing buildings, would have been predicted to collapse. Thus, these buildings are good candidates for additional numerical studies to predict their performance, assess the sensitivity of such predictions to uncertainties in building construction and modeling assumptions, and understand conditions that contribute to structural collapse.

vii. Previously repaired buildings – Several buildings visited were damaged in previous earthquakes and were subsequently repaired by epoxy injection, adding/replacing members, adding overlays to existing walls, etc. Detailed studies of these buildings will help assess the adequacy of various types of repairs, and provide guidance for future repair strategies.

viii. Instrumented buildings – Several buildings were instrumented prior to the earthquake, and others were instrumented following the event by Chilean and US researchers. These buildings in particular provide an excellent opportunity to benchmark current numerical analysis procedures and modeling assumptions.

ix. Ground motion directionality effects – It was observed that in various cities (Viña del Mar and Concepción) that damage tended to be more intense in a building oriented with a particular orientation with respect to the ground shaking. Several apartment complexes have nearly identical buildings that have different orientations and thus different damage. Studies of ground motion recordings, and of several buildings in an area will provide important insight into directionality effects during earthquakes and implications for design.

x. Slab coupling – Slabs and other elements not considered part of the lateral load resisting system were observed to have an effect on the overall building response, with significant local damage associated with the overall movement of the building. The impact of elements not normally considered part of the lateral load system on response and damage should be studied.

Hooper (ASCE) then discussed the reconnaissance by the ASCE team and their observations regarding code implications, with focus on ASCE 7 and ASCE 41. He indicated that the team was in the process of preparing a report on their findings. Topics mentioned at this meeting include:

a. Sites Visited by ASCE Team
    i. Santiago
    ii. Valparaiso
    iii. Viña Del Mar
    iv. Talca
    v. Concepción

b. Damage observed and issues raised
    i. Santiago
        - Many damages to walls were observed (similar to reported above by the EERI LFE team) associated with lack of transverse reinforcement in boundary elements, light reinforcement of wall panels (localized crushing and buckling or facture of longitudinal reinforcement), discontinuities (flag wall configurations), and so on.

- Significant damage was observed in nonstructural components including:
  - Cladding and partitions were heavily damaged. Cladding fell from buildings.
  - Cast-in-place and prefabricated stairs acted as unintentional structural elements and had extensive damage.

ii. Viña del Mar

- Many buildings heavily damaged, but did not collapse. Damage was concentrated in certain geographic regions of the city, which suggests the role of local soil effects should be studied.
- Setbacks in walls and some wall configurations (L and T shaped walls) lead to localized crushing of walls that extended across a wall at single elevation. Examples included crushing across the top and bottom of the wall. Longitudinal bars in walls show evidence of tensile elongation and fracture that appears to be associated with several cycles of buckling and re-straightening.
- Damage to intentional or unintentional coupling beams
  - Doors located over structural and nonstructural elements like coupling beams often jammed and were not designed to accommodate the transient and permanent deformation of the structure. This resulted in a life safety egress issue – many doors had to be forcibly opened to let occupants out.
- Different behavior was observed in similar buildings located near one another – this may be partially due to directionality effects, but other issues may have also influenced responses.
- Some older buildings were damaged as well as new ones, so a comparative ASCE 41-oriented study of the damages observed in newer and older buildings would be fruitful given the differences in design approach, configuration, detailing, etc.
- Behavior of previously retrofit or repaired buildings is possible as damage was observed in several of these buildings. Damage was observed in buildings having overlays added on existing walls, buildings having epoxy injected into cracks following previous earthquakes, as well as other types of repairs.
- The question of the ability of a building to resist the cumulative effects of multiple earthquakes, or a main shock and many aftershocks is raised by this earthquake and deserves further study.

iii. Talca

- Modern buildings did well.
- Significant damage observed in adobe and URM construction.
- Examples of directionality in building damage. For example, a building complex constructed perhaps in the1960's, consisted of more than 10 nearly identical buildings. There are clear patterns of damage, with buildings oriented in one direction having consistent damage, but buildings aligned orthogonally having consistent but far different damage patterns.

11:30 AM **5. Supplementary discussion by Chilean engineers**

Bonelli discussed recent research in Chile and elsewhere related to facture of reinforcing bars in tension and during lateral buckling. Tensile elongation of bars prior to compression can reduce their fracture capacity. Bonelli also reviewed information related to the confined core area available for different size members, and suggested that there may be a need in Chile for a minimum thickness wall to achieve a desired confinement efficiency. He also discussed the role of wall configuration (rectangular or T shaped) on the bar strain demands, and the impact of T and other similarly shaped walls on the ductility of a wall. Further study and incorporation of these and other findings into code provisions for walls were recommended.

Saavedra noted that Edificio Acapulco in Viña del Mar was repaired following the 1985 earthquake, making extensive use of epoxy injection for the repairs. This approximately 18 story building appears to have performed well from the outside during the 2010 event, but there is widespread local structural damage including some, like crushing of an exterior wall within the depth of the slab and crushing of lightly reinforced shear walls with resultant buckling of boundary and web longitudinal reinforcement, that was not observed in the 1985 earthquake. This suggests the need for minimum reinforcement of walls. It is believed that configuration irregularities are strongly related to damage type and location. Saavedra notes that recent geotechnical studies suggest that contrary to current code design spectra that the spectra for this area may have two peaks, one of which is likely in the fundamental period range for this building.

Lagos discussed issues relate to three topics: building location (soil effects), architectural and engineering design, and construction (excavation and compaction of soils, quality of materials, calculation of loads, inspection).

a. With regards to effect of soil conditions, he noted soil at some locations appear to be misclassified. There are four soil classifications in the Chilean code, including rock sites and three types of soils. There is a large difference in the spectral shapes and the amplitudes of spectral acceleration depending on the soil classification. He indicated that many engineers based soil classifications on blow count (N values) for the site, but more recent geotechnical studies based on shear wave velocity would suggest classification based on a softer soil condition would be appropriate. This can double the design forces and displacements for many buildings. He indicated that some sites consist of gravel layers over soft and deep soil layers, and this results in the sites responding like soil type 3 rather than type 2. Some topographical effects were noted, including basin and other soil effects of buildings located at the middle or edge of a valley between mountains, or on the mountain itself.

b. With regards to architectural design Lagos noted that the first stories of many buildings had fewer structural walls than the upper floors due to architectural constraints, and this resulted in discontinuous walls. Damage was observed in these areas, due to the reduced number of walls or the transfer of forces from the walls to the supporting elements. This trend also resulted in a number of irregularities in the configuration of individual walls, such as the wall set back in the first story (“flag-shaped” walls).

c. With regards to structural engineering design, Lagos noted that there remain significant uncertainties in how to model various structural elements and conditions. Recommendations for member properties over their full range of behavior need to be evaluated. Engineers generally assume fixed base conditions for the analysis of a building. However, base flexibility increases drift and this may account for the increased damage observed to nonstructural elements. He noted that damage associated with wall overturning moments seem more important than previously inferred from earlier earthquakes. As mentioned previously by others, the area of walls as a fraction of the total floor area has remained about constant (and higher than used in the US), but the number of stories has increased significantly, resulting in higher axial stresses in the walls.

While computer programs used typically give good estimates of member or global behavior, they are not capable of simulating the stresses and deformations in transition regions near discontinuities or irregularities in the structural system. He indicates that engineers tend to believe without question output from elastic computer programs, and this has had the effect of making buildings more irregular and elements having high stresses.

d. With regards to construction, he noted improvements could be made in individual cases, but these were not the principal reasons for the observed damages.

Juan Carlos de la Llera offered several comments about ground motions, structural behavior and other topics.

a. He noted that the strong motion accelerograms suggest the occurrence of two ruptures that overlap, resulting in a particularly long duration of strong shaking, and some atypical dynamic characteristics. The long duration greatly increased the likely number of cycles a building experienced, and this would have important structural consequences, such as the progressive crushing of walls. As opposed to the 1985 event, rupture for this event started in the south and propagated towards north, and then another rupture started. The long length and duration of the ruptures resulted in Doppler (directivity) effects in the resulting ground motions, resulting in a different frequency content compared to records from earlier earthquakes. GPS measurements show large permanent ground displacements (in some places as much as 3.5 m). The current code spectrum has a rapid decay at long periods, and this needs to be corrected (this was recently corrected for seismically isolated structures). Implications of these important subduction zone records for the Pacific Northwest in the US should be identified. Comments from participants indicated that USGS and PEER's NGA program were interested in looking into these design spectrum issues.

b. With regards to structural behavior, de la Llera noted:

   i. There is strong evidence of performance influenced by the overall 3D responses of structural systems as well as by local behavior of local members and connections (e.g., lack of transverse confinement in boundary elements, discontinuities, etc). He also noted that the R factor used in Chilean design (6-7) assumes that energy can be dissipated by the system. However, the real behavior did not reflect ductile response (in fact, many buildings were brittle), and the behavior was not consistent with the design expectations.

   ii. Designers in Chile are facing serious near-term problems with how to address repairs, retrofits and new construction projects. That is, damage occurred in buildings designed according to current codes, so what criteria or guidelines should be used? Boundary elements can have heavy longitudinal reinforcement, and detailing of transverse reinforcement may be difficult (what details should be used?). What detailing should be provided at regions of near discontinuities (set backs, elements supporting discontinuous walls, around openings, etc.)? While computers address overall dynamic response and member forces, they provide little guidance on local detailing requirements.

   iii. Studies are needed of buildings that did not suffer damage. These were designed using the same code and may include the same details. While they survived this earthquake, are they adequate for future earthquakes that may subject individual buildings to high seismic demands?

   iv. Slabs contributed to response and should be considered as a seismic element.

c. General comments include:

i. Some systematic damage was not immediately reported after the earthquake. Schools are an example, where many schools throughout the heavily shaken area are damaged, and 40 or more need to be demolished. There is also anecdotal evidence that numerous buildings that showed no superficial damage have now been discovered to have suffered significant damage that was not first apparent.

ii. The public was not prepared to expect the severe structural and nonstructural damage that occurred. In some cases, some major businesses, universities and government agencies lost lots of critical information and important equipment. Nonstructural elements (ceilings, partitions, cladding, etc.) and critical equipment need to be controlled in a more engineered fashion – this includes proper anchorage and bracing. See also paragraph v. below.

iii. Several precast structures have significant damage that should be looked at carefully as this form of construction may be more common in the future.

iv. There are many seismically isolated buildings in Chile, and while they did well compared to other types of structures, they should be studied within the context of their design criteria and performance expectations.

v. Greater efforts are needed to engage the public and officials in identifying appropriate performance goals for buildings in general, and buildings that are important to the public in some fashion (might endanger nearby buildings, provide housing for many people, house important business or public functions). Engineers should better inform the public of expected performance associated with current building codes.

vi. The widespread use of computer analysis software that assumes linear elastic behavior has resulted in structural engineers having the confidence to use members that are more heavily loaded, more slender or more irregular than before. The limitations of computer software and numerical models needs to be better appreciated to avoid damage of the type observed in this earthquake.

12:00 PM **6. Additional observations not covered by previous speakers**

Medina reinforced several earlier items discussed, especially:

a. Directional effects were important.

b. Uncertainties in modeling (programs may give different results depending on modeling assumptions, are rigid diaphragm assumptions appropriate, implications of soil-structure interaction, etc.).

c. The high level of nonstructural damage was not expected by the public. These elements should be subjected to an engineered approach to design.

12:10 PM **7. Lunch (with informal discussion)**

1:00 PM **8. Discussion of *suggested study topics* submitted by attendees**

Prior to the meeting, participants suggested 22 topics for possible study. Each individual who submitted a topic was provided a brief time in the meeting to describe the salient issues addressed by the suggested topic, and a short general discussion by the participants followed. These suggested topics are presented in Appendix D, along with some comments by the participants.

It was suggested by Mahin that some topics were not listed because they fell outside of the purpose of the current meeting. These included investigations on the economic and other impacts of the damage that occurred, processes used to decide whether to repair or demolish heavily damaged buildings, the costs and disruption (downtime, relocation expenses, etc.) of repair or replacement work, the role of insurance companies in deciding repair/rebuilding strategies, and so on. Given the short time participants had to prepare for the meeting, it is also possible that some salient topics have been overlooked in the list.

2:00 PM **9. Enumeration of code implications (ASCE 7 and ACI 318) that might be inferred from the earthquake and its effects**

Based on previous presentations and first hand reconnaissance observations, participants identified key implications for US building codes and recommendations, such as ASCE 7, ASCE 41 and ACI 318. These include in unranked order:

a. Ground motions definition and geotechnical issues:
   i. Effect of long duration of ground shaking.
   ii. Directionality/directivity effects.
   iii. Appropriateness of values used for T_L.
   iv. Attenuation relations used for subduction zone earthquakes.
   v. Design issues related to resisting effects of aftershocks.
   vi. Appropriateness of site modification factors for design spectra.
   vii. Double earthquake rupture effects.
   viii. Effect of co-seismic ground displacements on structural performance.

b. Architectural issues
   i. Extensive damage to intentional and unintentional coupling girders.
      - Nonstructural and MEP elements often buried in coupling girders to gain access from hallways to apartments. This produces extensive damage.
      - Difficulty in opening doors supported on coupling beams. These nonstructural elements need to accommodate the inelastic deformations implied by the design.
   ii. Stairs (concrete and steel). What performance is expected of stairs since they are needed for emergency egress?
   iii. Nonstructural elements suffer extensive damage and should be treated with a more engineered approach.
   iv. Damage to unrestrained contents can result in substantial disruption to function of structure and create substantial economic loss even if structure is not damaged.

c. Structural issues
   i. Repair of severely damaged buildings vs. demolition. What is the efficacy of various repair approaches (epoxy, bar replacement, member replacement, etc.)?

ii. Behavior of frame buildings.

iii. Design requirements for anchors for structural and nonstructural elements.

iv. Concrete wall design issues:

a. Axial stress limits/ neutral axis limit.

b. Wall boundary detailing and triggers for transverse confinement boundary elements.

c. Wall cross-section shape (T, L, etc.).

d. Lap splice failures.

e. Minimum longitudinal reinforcement requirements.

f. Flag walls.

g. Very thin walls - confinement / buckling issues.

h. Higher mode effects.

i. Fatigue in long duration earthquakes.

v. Precast structures.

vi. Effects of foundation rotation and deformations.

vii. Configuration and irregularities of structural system in plan and elevation.

viii. Participation of building components not part of the seismic-load-resisting system (non-frame columns, slabs linking walls, etc.)

ix. Displacement estimation procedures, including spectra, C_d, damping values, etc.

x. Appropriateness of R factor for *ordinary* structural walls in relation to desirable failure modes. Given observed performance is behavior of walls without minimum amounts of transverse reinforcement adequate?

xi. Appropriateness of single flexural hinge concept for walls in tall buildings. Distribution of lateral forces used for design over height of building. Appropriateness of value of F_t.

xii. Design of diaphragms.

xiii. Inadequate slider support length and anchorage for structural elements.

xiv. Collapse prediction.

xv. Minimum base shear and drift limit requirements.

xvi. Performance requirements for taller buildings (falling on adjacent buildings) and other high-risk category buildings.

xvii. Stairs acting as unintentional diagonal bracing.

xviii. Requirements for modeling / sensitivity analyses / local demands at discontinuities, transitions and supports.

d. Existing Buildings

i. Impact of cumulative damage from multiple earthquakes and aftershocks.

ii. Effectiveness of previous repairs.

2:45 PM **10. Identify specific needed data, including building drawings, detailed damage surveys, and digital ground motion records. Identify specific buildings where appropriate.**

The participants then discussed the specific information needed to carry out the proposed investigations. The information needed (and some comments) include:

a. Ground motion records

   i. It was noted by several Chilean participants that there was a reasonable chance to obtain records from the University of Chile in short time, pending completion of negotiations currently underway with the government.

   ii. There are some other records for dams, industrial facilities, and particular buildings. Getting these records will take longer and may be more problematic (depending on the interest of the owner of the instrument).

   iii. May be able to simulate numerically ground shaking at sites where no instruments are available by developing a fault rupture model and calibrating it against available records located near the site of interest. Such simulated records may only include meaningful frequency content less than one Hertz. No such model is known to have been developed yet for the Chilean Subduction Zone Fault System.

b. Data from buildings to be demolished in near future

   i. Identify buildings be demolished soon, and gather drawings, carry out damage mapping, and get material properties if possible.

   ii. Identify other buildings of interest that might be demolished later.

c. Building drawings, associated specs, material properties and geotechnical information

   i. Information for some buildings may already be available, but some owners may not be interested in sharing information for various reasons (e.g., legal, public relations, etc.).

   ii. Can ask to obtain particular drawings of interest. Engineers will need to get permission from owners. City governments may be willing to give copies of drawings, but these may not reflect as built conditions.

   iii. Specific buildings of interest by city

      1. Concepción

         - O'Higgins
         - Rio Alto
         - Plaza del Rio
         - Centro Major
         - Civic
         - Araucana
         - 152 Castellon Salas
         - Boquemar
         - Olas
         - Lincoyan 440 - Torre Libertad
         - Plaza Mayor 2
         - Sodimac Warehouse (in Coronel)

      2. Santiago

         - Emerald
         - 2150 Central Park
         - 1631 Hipodromo
         - Sol Oriente I and II
         - Patio Mayor I-4, Enterprise
         - Chilean Chamber of Construction
         - Various tall buildings
         - 3 buildings with aftershock information
         - ACHS (seismic isolated building per

City Bonelli)

3. Viña del Mar
    - Toledo
    - Festival
    - Coral
    - Torre del Mar
    - Bahia
    - Rio Petrohue
    - Malaga
    - Trenrife
    - Acapulco
    - Rio Imperial
    - ACHS (seismic isolated building per Bonelli)
    - Hanga Roa
    - Tricahue
    - Oasis
4. Chilan
    - Torre Mayor
5. Talca
    - Hall of Justice
    - Amalfi
6. For all of the above locations, where possible get drawings of nearby buildings that were not damaged.

3:30 PM **11. Suggested study topic ranking, followed by scoping discussion.**

The meeting participants agreed that the behavior of buildings during the February Chilean earthquake raises several important questions about the adequacy of current building codes and standards and about the ability of current computational methods used by engineers to assess building performance. Particularly since the Chilean building code has adopted by reference key aspects of U.S. model building codes, this earthquake provides the first opportunity to observe the effectiveness of many recent U.S. model building code advances. *The real world laboratory experiment provided by the 2010 Chilean earthquake provides a unique opportunity to carry out studies needed to identify and mitigate deficiencies in our building codes and standards (those deficiencies may also exist in other areas of the world that are prone to significant earthquakes).*

Those assembled agree that joint collaborative research activities including US and Chilean engineers and researchers is the most effective and practical way of accelerating progress in understanding the structural performance observed in the 2010 Chilean earthquake and carrying out research and other investigations needed to improve seismic-resistant design codes and standards. The participants encourage funding agencies in the US and Chile to provide support to enable the high priority topics identified to be addressed in a timely fashion.

The following five interrelated research activities are considered **urgent, time-sensitive** needs to improve code provisions for seismic design and evaluation. They include applicable specific, detailed study topics from the 22 topics listed in Appendix D, and draw upon extensive discussions by the meeting participants. The topics presented in Appendix D are cross-referenced with the proposed activities using italicized listings in each activity area. The activities noted below generally pertain to both new building design and to evaluating and strengthening existing buildings.

A. Systematic collection, synthesis and analysis of perishable data from buildings in Concepción (and elsewhere in Chile). Immediate efforts are needed to ascertain accessibility to drawings and other information. Many buildings have been slated for rapid demolition. Appropriate buildings for immediate study include:

   a. Central Mayor
   b. 1165 Freire (not perishable)
   c. O'Higgins
   d. Alto Rio
   e. Plaza del Rio – 1345 Salas
   f. Los Carreras 1535
   g. Licoyan 440
   h. Caupolican 518
   i. Others including Buscomar, Olas, Alto Huerto in San Pedro

   Appendix D topics: 1, 2, 6, 9, 11-15, 17

B. Studies of ground motions characteristics at key sites. This includes:

   a. Gathering digital strong motion data (this may involve processing of some analog records).

   b. Use data to understand shaking intensity at key sites.

   c. Relate apparent intensity of shaking, permanent ground displacements and design criteria to damage observed at site.

   Appendix D topics: 7, 8, 10, 22

C. Detailed study of several damaged and undamaged buildings; study of collapse prediction capabilities. It is expected that a statistically relevant number of buildings will be selected for these studies, and selection of these buildings be coordinated so that the effect on damage prediction of various structural configurations, types of irregularity, structural details, ground motion characteristics, site conditions, modeling assumptions and simulation procedures can be identified and compared. Studies should identify commonalities and differences between US and Chilean codes and design practices, and issues relevant to improving specific provisions in US and Chilean building codes.

   Appendix D topics: 1, 4, 6, 9 - 18, 20

D. Identify improved design requirements for design and detailing, especially with regards to concrete wall boundaries. For example, improved guidance is needed related to:

   1. When is confinement required?

   2. What are the requirements for longitudinal and transverse reinforcement of boundary elements?

   3. Should axial stress or neutral axis limits be established for structural walls?

   4. Are design provisions for irregular wall configurations and cross-sections adequate?

   5. Should there be limitations on wall slenderness?

   Appendix D topics: 1, 4, 8, 9, 11, 12, 15, 19 – 21

E. Establish Chile post-earthquake clearinghouse -- Provide convenient database for investigators and others to get information about ground motions, buildings and damages, and share their findings with others.

   Appendix D topics: All, 5

Several other research activities that are somewhat more long-term in nature were identified that are considered **essential** for resolving model building code issues. These activities have also been cross-referenced with applicable detailed study topics found in Appendix D.

F. Develop and validate advanced numerical models and computational procedures for simulation of performance of buildings containing RC structural walls over the complete range of behavior, from elastic response to collapse. New test programs may be needed to obtain data needed to develop and evaluate the adequacy of these simulation capabilities.

Appendix D topics: 1, 6, 12, 13, 14, 16

G. Devise a comprehensive rehabilitation strategy for damaged shear wall buildings.

Appendix D topics: 13

H. Study and improve behavior of anchors for structural components and nonstructural elements.

Appendix D topics: NA

I. Improve procedures for estimating shaking intensity as a function of site/basin effects and for buildings subjected to shaking from subduction zone fault ruptures

Appendix D topics: 10, 22

J. Improve procedures for seismic detailing and design of non-structural nonstructural elements, laboratory and other equipment, contents to help minimize losses and post-earthquake disruption.

Appendix D topics: 3, 18 ,21

5:15 PM **12. Adjourn**

Hayes and Moehle thanked all of the participants for attending the meeting and for their active participation. Hayes noted that the effectiveness of any U.S. research that is undertaken will be enhanced if the NEHRP agencies (FEMA, NIST, NSF, USGS) work in a cooperative and coordinated manner, within their respective NEHRP mission areas. The Chilean participants expressed appreciation for being included in the meeting and for the opportunity to interact with US engineers and investigators at this and future meeting as well as in the joint US-Chile investigations on the code implications of the 27 February 2010 earthquake.

Appendix A: Meeting Participants

The 27 February 2010 Chile Earthquake: Implications for U.S. Building Codes and Standards

Invited Attendees		Work Affiliation	Team Affiliation	x – in person o - online	Contact
Patricio	Bonelli	U. Santa Maria, Chile	Local	x	patricio.bonelli@usm.cl
David	Bonneville	Degenkolb	ASCE	x	dbonneville@degenkolb.com
Juan Carlos	De La Llera	U. Catolica de Chile	Local	o	jcllera@ing.puc.cl
Jeff	Dragovich	NIST	EERI LFE	x	jeffrey.dragovich@nist.gov
Ron	Hamburger	SGH	ASCE	x	rohamburger@sgh.com
Bob	Hanson	FEMA consultant	-	x	RDHanson2@aol.com
Jay	Harris	NIST	ASCE	x	john.harris@nist.gov
Jim	Harris	J.R. Harris & Co	ASCE	x	Jim.Harris@jrharrisandco.com
Jack	Hayes	NIST (NEHRP Director)	-	x	jack.hayes@nist.gov
John	Heintz	ATC	ASCE	x	jheintz@atcouncil.org
John	Hooper	Magnusson and Klemencic	ASCE	x	jhooper@mka.com
René	Lagos	René Lagos y Asociados, Santiago, Chile	Local	x	rlagos@lagos-ing.com
Nico	Luco	USGS	-	x	nluco@usgs.gov
Steve	Mahin	UC Berkeley / PEER	-	x	mahin@berkeley.edu
Mike	Mahoney	FEMA	EERI LFE	x	mike.mahoney@dhs.gov
Francisco	Medina	FME Engineering	-	x	francisco@cal.berkeley.edu
Jack	Moehle	UC Berkeley	EERI LFE	x	moehle@berkeley.edu
Farzad	Naeim	JAMA	LATBSDC	o	farzad@johnmartin.com
Jim	Rossberg	ASCE	ASCE	x	jrossberg@asce.org
Manual	Saavedra S	Ruiz-Saavedra Eng., Santiago, Chile	ASCE	x	secretaria@ruiz-saavedra.com
John	Wallace	UCLA	EERI LFE	x	wallacej@ucla.edu

Invitees William Holmes (Rutherford & Chekene, San Francisco), Joy Pauschke (NSF) and M.P. Singh (NSF) were unable to attend the meeting.

Appendix B: Goals for Meeting

The 27 February 2010 Chile Earthquake: Implications for U.S. Building Codes and Standards

The purpose of the meeting is to analyze possible shortcomings and support improvements to U.S. model building codes through observations and studies of the 27 February 2010 Chile earthquake by pursuing the following actions:

1. Share observations of leaders of various U.S. reconnaissance teams (ASCE, EERI LFE, LA Tall Buildings Structural Design Council) and Chilean engineers.
2. Discuss possible issues for U.S. building codes.
3. Identify future studies that will clarify needed changes to U.S. building codes.
4. Identify specific needed data for future studies, including building drawings, detailed damage surveys, and digital ground motion records. Identify specific buildings where appropriate.
5. Develop priority listing of future studies, including details such as timeline, costs, and likely characteristics of study team (academic, practicing engineer, field study, etc.)
6. Identify how best to archive the data and other findings for public access by researchers.

Appendix C: Tentative Agenda

The 27 February 2010 Chile Earthquake: Implications for U.S. Building Codes and Standards

Tentative Agenda

Time	Topic	Discussion Leader(s)
1000	6. Welcome and introductions	Hayes, Moehle
1015	7. Meeting objectives and agenda	Hayes, Moehle
1030	8. Reconnaissance summaries by EERI LFE and ASCE teams. Where did they go? What buildings visited? What are the principal observations/questions related to our codes?	Wallace, Hooper
1130	9. Supplementary discussion by Chilean engineers	Bonelli, Boroschek, De La Llera, Lagos
1200	10. Lunch with continuing discussion	All
1245	11. Additional observations not covered by previous speakers	All
1300	12. Enumeration of code implications (ASCE 7 and ACI 318) that might be inferred from the earthquake and its effects	Moehle
1330	13. Discussion of *suggested study topics* submitted by attendees	Moehle
1430	14. Identify specific needed data, including building drawings, detailed damage surveys, and digital ground motion records. Identify specific buildings where appropriate.	Moehle
1530	15. *Suggested study topic* ranking, followed by scoping discussion.	Moehle
1630	16. Data archiving	Moehle
1700	17. Adjourn	

Appendix D: Suggested Study Topics

Participants submitted twenty-one topics for detailed study, and an additional topic was developed during the meeting. These ideas were presented by the proponent and discussed by the meeting participants.

Table D.1 provides a summary of the topics, and Tables D.2 contains a more detailed description of the topic, the approach to be taken, and an estimate of the time and funding needed to carry out the suggested study.

Table D.1 Summary List of Suggested Study Topics

Topic No.	Topic	Proponent
1	Investigation of minimum longitudinal reinforcement requirements in wall boundaries	Jack Moehle
2	Detailed documentation of building damage	Jack Moehle
3	Seismic Protection of “Laboratory Equipment” as specified in ASCE 7, Table 13.5-1	William T. Holmes and Mary Comerio
4	Study of the ACI 318 trigger for boundary element confinement	Jack Moehle
5	Chile Post-Earthquake Information Clearinghouse	Jeff Dragovich
6	Evaluation of Reinforced Concrete Wall Models for Seismic Response	Jeff Dragovich
7	Comparison of Ground Motion Spectra in Chile with the USGS Seismic Hazards	Jeff Dragovich
8	Observations from the February 27th, 2010 Great Chilean Earthquake and their Effect on the Behavior and Design of Ordinary Slender Reinforced Concrete Structural Walls in SDC C	Jay Harris
9	Critical Evaluation of Structural Irregularity Provisions in ASCE 7-10	Jay Harris
10	Impact of Duration of Strong Ground Motion on Performance of Buildings	Farzad Naeim
11	Impact of Configuration and Irregularities on Performance of Buildings	Farzad Naeim
12	Effective seismic energy dissipation strategies for shear wall buildings	Juan Carlos de la Llera
13	Comprehensive retrofit strategies for shear wall buildings	Juan Carlos de la Llera
14	Study of the building collapse	Jack Moehle
15	Axial stress limit for special structural walls	Jack Moehle
16	Collapse Prediction of Wall Structures	Ron Hamburger
17	Vertical distribution of seismic design forces	Ron Hamburger
18	Performance goals for residential buildings	Ron Hamburger
19	Study Minimum Dimensions of Confined Cores Within Shear Walls	Jim Harris
20	Compare Variation Building Code Design Objectives with Variation in Seismic Ground Shaking	Jim Harris
21	Compare Drift Limits in Chilean and US Practice and Assess the Effect of the Differences	Jim Harris
22	Effect of Co-Seismic Ground Displacement on Building Performance	Farzad Naeim

Table D.2 Detailed Descriptions of Suggested Study Topics

TOPIC NO. 1	Investigation of minimum longitudinal reinforcement requirements in wall boundaries.
PROPONENT:	Jack Moehle (UC Berkeley)
REASON STATEMENT: (100 words or fewer)	Many wall boundaries showed fractured longitudinal bars, and many showed buckled bars. There is reason to suspect that the wall section cracked and the cracks remained localized because of low reinforcement ratio, leading to fractured bars in some cases and leading in other cases to bar buckling and cover spalling upon deformation reversal. This could have resulted in a notch that propagated to result in the spalled walls we found after the earthquake. Current US codes effectively do not cover this condition.
APPROACH (100 words or fewer)	1. Conduct statistical study of wall boundary reinforcement ratios and failure modes in many buildings. 2. Simple numerical study plus comparison with available laboratory test data. 3. Supplementary tests on tension-compression members representative of wall boundaries or tests of actual walls. Investigate both traditional cyclic loading and loading in large initial amplitudes.
ESTIMATED COST	1 + 2 ~ $20,000. 3 ~ $100,000 - $150,000
TIMELINE	1 + 2 ~ 6 months 3 ~ 12 months
DISCUSSION COMMENTS:	Hamburger and others noted that there were some walls with relatively heavy longitudinal reinforcement in the boundary elements that had similar damage. Generally agreed that statistical and numerical studies of damage is critically needed for a statistically relevant number of buildings to characterize this damage. Numerical and experimental studies should be undertaken to identify required code changes, if any.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 2	Detailed documentation of building damage
PROPONENT:	Jack Moehle (UC Berkeley)
REASON STATEMENT: (100 words or fewer)	Several buildings of interest in Concepción will be demolished in about two months. Building drawings are available and buildings can be accessed for detailed damage documentation. Documentation will be invaluable to future studies of the behavior of wall buildings during earthquakes, including code-related studies.
APPROACH (100 words or fewer)	1. Select target buildings. 2. Obtain drawings. 3. With drawings in hand, conduct detailed damage surveys of selected buildings.
ESTIMATED COST	~ $10,000 to $20,000 per building. Perhaps less if less detailed documentation is considered sufficient.
TIMELINE	2 months (must be completed within 2 months from now)
DISCUSSION COMMENTS:	Estimated cost per building may be as low as $2,000-$3,000 per building, if material testing and highly detailed documentation is not required. Can involved local students and engineers working in combination with US investigators. James Harris commented with general agreement that this was a critical and good investment.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 3:	Seismic Protection of "Laboratory Equipment" as specified in ASCE 7, Table 13.5-1
PROPONENT:	William T. Holmes (Rutherford and Chekene) and Mary Comerio (UC Berkeley)
REASON STATEMENT: (100 words or fewer)	Significant loss to equipment, cultures, enzymes, and other frozen samples occurred at U. Concepcion, Talca, and U. Chile, Santiago. Direct loss of equipment about $500,000 at each location with long lead times to replace. More importantly, much research lost. CONICYT (Chile's main science funding agency) says, "It is a tremendous loss for us, for the country, and for science to see years of investigation destroyed." Reference: http://www.scidev.net/en/news/chile-s-earthquake-knocks-out-research-labs.html Prof. Comerio also has contacts with laboratory researchers in L'Aquila, Italy that have similar experience. The U.S. has enormous square footage of similar laboratories located in regions of high seismicity.
APPROACH (100 words or fewer)	Document actual conditions of losses in Chile and L'Aquila, Italy. Shake table test various anchorage or other protection methods for large -80 freezers, incubators, and other critical lab equipment. Clarify code requirements. Document ancillary critical systems that are needed to protect research. Develop manual for "Seismic Protection of Laboratory Equipment and Research Products."
ESTIMATED COST	$300,000
TIMELINE	2 years
DISCUSSION COMMENTS:	Generally observed that equipment and contents of many facilities such as those described above were heavily damaged, in spite of taking precautions similar to or better than in the US. The participants commented that this was an important problem, but that priority should generally be given to study topics involving code deficiencies related to life safety.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 4:	Study of the ACI 318 trigger for boundary element confinement
PROPONENT:	Jack Moehle (UC Berkeley)
REASON STATEMENT: (100 words or fewer)	In 1995, partly as an outcome of research on the 1985 Chile earthquake, ACI 318 adopted new provisions for when boundary element confinement is required. The procedure is based on the design displacement and a set of simplifying assumptions. The approach might be questioned: Should we use DBE or MCE displacement? Are the simplifying assumptions effective? Because an unconfined bearing wall can be fairly brittle, should Ω_0 factor apply to the determination? Should a *special* structural wall always be confined in the hinge region, with a *less-than-special* designation for unconfined walls?
APPROACH (100 words or fewer)	Select a statistically meaningful sample of representative wall buildings for which ground shaking can be estimated and performance can be documented, obtain structural drawings, and either construct or obtain ETABS models. Calculate whether confinement would be required per ACI requirements and compare with performance.
ESTIMATED COST	$5,000 - $10,000 per building, about 30 buildings, for a total of up to $300,000.
TIMELINE	18 months
DISCUSSION COMMENTS:	

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 5:	Chile Post-Earthquake Information Clearinghouse
PROPONENT:	Jeff Dragovich (NIST)
REASON STATEMENT: (100 words or fewer)	The Chile earthquake data-gathering effort will potentially result in a significant amount of information. The "clear" dissemination of this information is key to support researchers in future grant proposal preparation and analytical studies. The information envisioned includes photographs, ground motion data, instrumented building data, detailed building drawings, computer models (e.g., ETABS) and geographic location data via Google Earth of all pertinent information. If deemed appropriate, a blog mechanism could be implemented for select information for user commentaries.
APPROACH (100 words or fewer)	The information would be stored in a database available via the internet. The technology used could possibly be web pages served on www.nehrp.gov/Chile. However, SharePoint and Wiki solutions would also be evaluated. A mechanism would be developed for users to submit data for inclusion in the database.
ESTIMATED COST	NIST Internal
TIMELINE	3 Months
DISCUSSION COMMENTS:	General agreement that this would be useful to facilitate the investigations. It was noted that PEER or EERI might be able to assist. de la Llera commented that there might be legal and other issues in getting drawings of buildings and detailed information on building damage. Many owners appear to not want information about their structures made public or used for research investigations.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 6:	Evaluation of Reinforced Concrete Wall Models for Seismic Response
PROPONENT:	Jeff Dragovich (NIST)
REASON STATEMENT: (100 words or fewer)	The goal of this project is to evaluate and improve reinforced concrete wall modeling capabilities. As noted during the 2010 Chile Earthquake reconnaissance, the failure mode of many reinforced concrete walls would most likely not be predicted using current commercial and research finite element software.
APPROACH (100 words or fewer)	The project tasks include: 1. Identify candidate buildings in Chile, and associated required information, to be used as a test bed. 2. Collect existing experimental data related to reinforced concrete wall cyclic response. 3. Evaluate (1) and (2) using available nonlinear finite element software, such as: SAP2000, LS-DYNA, and OpenSees. 4. Evaluate effectiveness of (3) in predicting the results of (1) and (2). 5. Identify "research" models that may predict observed response. This may require custom software development in order to implement these models. 6. Evaluate (1) and (2) using the models identified in (5). 7. Using the results of (4) and (6), rank the effectiveness of the models, and conditions when the models provide a satisfactory prediction of response. 8. Using (7), propose a new model if one is apparent.
ESTIMATED COST	NIST internal.
TIMELINE	1 year.
DISCUSSION COMMENTS:	Jim Harris, Hamburger and others commented positively about this topic. It was noted that there are likely to be many investigators involved in such studies, and that some of the tasks identified could be incorporated in a coordinated fashion in to individual studies of particular buildings. The results could also guide in identifying future tests needed to be done.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 7:	Comparison of Ground Motion Spectra in Chile with the USGS Seismic Hazards
PROPONENT:	Jeff Dragovich (NIST)
REASON STATEMENT: (100 words or fewer)	How does the ground motion in Santiago compare with the USGS mapped (2/3) MCE_R in downtown Seattle, for example? The rough evaluation of whether a building performed “good” or “inadequate” depends on our frame of reference. Right now, we do not really have a handle on how the ground motion in Santiago, Concepción, etc relate to the earthquake return periods in various west coast locations in the USA. This information is fundamental to evaluating whether the observed structural response is “good” or “inadequate.” For example if a building were in a location that is equivalent to a 50%/50 year in Portland, and all the coupling beams were completely destroyed and the walls blown-out, that would be “inadequate.” However, if it were equivalent to 2*MCE_R and the building is still standing, then that could be considered the “design intent.”
APPROACH (100 words or fewer)	The approach envisioned would be at a minimum a direct comparison of PGA, and acceleration spectral shapes. It is expected that this rudimentary approach will be inadequate, and that a more elaborate method be employed such as velocity, displacement, energy spectra, Housner spectrum intensity, or any other means the investigator comes up with.
ESTIMATED COST	$10,000-$20,000 (approximate)
TIMELINE	1-2 Months
DISCUSSION COMMENTS:	Comparison of results obtained related to likely damage in US cities subjected to similar shaking would be useful, as would an assessment of current attenuation relationships for subduction zone events. Hooper commented positively about such studies related to the Pacific Northwest of the US. Mahin indicated that PEER is starting an NGA-subduction as part of its Earthquake Predictive Equations project for the Global Earthquake Model (GEM) program. This will include improving attenuation relations by incorporating records from the 2010 Chilean and other recent subduction zone events.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 8:	Observations from the February 27^{th}, 2010 Great Chilean Earthquake and their Effect on the Behavior and Design of Ordinary Slender Reinforced Concrete Structural Walls in SDC C
PROPONENT:	Jay Harris (NIST)
REASON STATEMENT: (100 words or fewer)	Ordinary structural walls in SDC C do not require detailing prescribed in ACI-318, Ch. 21. Seismic design typically controls concrete buildings up to 20 stories and walls tend to be thin, with high reinforcement ratios. Are these walls therefore at an undesirable risk given a MCE event? Are the h/t limits adequate for these walls? One quandary is when mapped spectral values indicate SDC D for a higher risk category (I_e > 1.0); however, a site-specific analysis is conducted to reduce the values to SDC C, even though a higher performance is required. Should spectral values include I_e (and r) in lieu of separation by Risk Category? Similarly, C_uT_a does not change the strength design period between ordinary and high risk category buildings at the same location. Should design period include I_e (and r)? Drift is usually not a concern for the above noted building heights.
APPROACH (100 words or fewer)	TBD
ESTIMATED COST	TBD; also depends on whether or not experimental studies are required.
TIMELINE	Up to 2 years
DISCUSSION COMMENTS:	General agreement on need for studies related to issues raised by this topic.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 9:	Critical Evaluation of Structural Irregularity Provisions in ASCE 7-10.
PROPONENT:	Jay Harris (NIST)
REASON STATEMENT: (100 words or fewer)	Detailed studies are needed to evaluate the irregularity provisions prescribed in ASCE 7-10, primarily torsional irregularities. Further, recently developed methodologies to determine seismic performance factors (e.g., FEMA P695) have not yet evaluated structural irregularities. This study may also include evaluation of detailing requirements of the gravity system.
APPROACH (100 words or fewer)	Conduct high-fidelity advanced analytical studies of certain buildings that exhibit structural irregularities per ASCE 7-10. Candidates, to list a few, are: 1) Torre O'Higgins, Concepción 2) Torre Aruacana, Concepción 3) Condominio Alto Rio, Concepción Analyze the as-built structure Redesign per ASCE 7-10 and analyze
ESTIMATED COST	TBD
TIMELINE	6 months per building
DISCUSSION COMMENTS:	Detailed studies of causes of damages were generally thought to be a critical need.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 10:	Impact of Duration of Strong Ground Motion on Performance of Buildings
PROPONENT:	Farzad Naeim (JAMA)
REASON STATEMENT: (100 words or fewer)	How much of the damage observed could be directly or indirectly attributed to the long duration of strong motion during Chile Earthquake? On several occasions main reinforcing bars were broken particularly those near a bent. Was this caused by low cycle fatigue? These issues are important for addressing the performance of buildings during future earthquakes as duration may be significantly shorter during moderate size events that are more frequent. We need to know what are design problems that can cause failure in any earthquake versus those that can only occur during mega M>8 or so events.
APPROACH (100 words or fewer)	Vary duration and the number of cycles as a part of study of each building to address the issue of strong ground motion duration impact
ESTIMATED COST	Additional $5,000-$10,000 budget for every building funded for modeling and studies
TIMELINE	3 to 6 months
DISCUSSION COMMENTS:	Several commented that not enough attention has been given to this topic recently, and issues of aftershocks and future re-occurrence of large shocks should be considered.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 11:	Impact of Configuration and Irregularities on Performance of Buildings
PROPONENT:	Farzad Naeim (JAMA)
REASON STATEMENT: (100 words or fewer)	How much of the damage observed could be directly or indirectly attributed to plan or elevation irregularities in the building? I am aware of one that apparently interruption of walls at a floor above the base could have had serious impact on performance. There are others that drastic changes in strength or stiffness could have contributed to the damage observed. Would the same type of damage occur if these configuration and irregularity issues did not exist?
APPROACH (100 words or fewer)	For every building studied, which exhibited a significant configuration or irregularity issue(s), eliminate the issue(s) and compare the performance of the revised model to the as-built model.
ESTIMATED COST	Additional $5,000-$10,000 budget for every building funded for modeling and studies
TIMELINE	6 months
DISCUSSION COMMENTS:	Similar to Topic 9

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 12:	Effective seismic energy dissipation strategies for shear wall buildings
PROPONENT:	Juan Carlos de la Llera (U. Catolica de Chile)
REASON STATEMENT: (100 words or fewer)	Common energy dissipation strategies do not work effectively in typical Chilean shear-wall (fish-bone) type buildings due to the deformed shape of cantilever walls, which involves rigid body rotations of story panels, bending of slabs, and smaller inter-story drifts. Therefore, we propose to investigate the extent by which these energy dissipation elements may control the observed brittle bending and compression failures associated with high axial cyclic stresses.
APPROACH (100 words or fewer)	1. Select and collect information of target buildings (~9) in different soil conditions 2. Create detailed structural building models in SAP and ANSYS 3. Reproduce shear wall failures using inelastic dynamic analysis 4. Evaluate different energy dissipation strategies in these structures 5. Compute predicted building response with selected energy dissipation strategies 6. Evaluate code implementation of these energy dissipation strategies
ESTIMATED COST	1 + 2 + 3~ $70,000 4 + 5 ~ $60,000 6 ~ $30,000
TIMELINE	1 + 2 + 3 ~ 12 months 4 + 5 + 6 ~ 12 months
DISCUSSION COMMENTS:	It was noted by several that the buildings did not in general behave in a desired ductile manner. Thus, improving details, as well as the system would be useful. de la Llera also this relates to the addition of supplemental energy dissipation devices such as yielding devices and fluid viscous dampers.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 13:	Comprehensive retrofit strategies for shear wall buildings
PROPONENT:	Juan Carlos de la Llera (U. Catolica de Chile)
REASON STATEMENT: (100 words or fewer)	Different techniques are being currently proposed to recuperate damaged shear wall type buildings in Chile. Depending on the structure and its condition, these techniques involve special adjustable shoring, straightening of leaning structures, retrofitting and strengthening damaged shear walls and replacement other vertical elements, and introducing optimal energy dissipation devices. Documentation and analysis of the information relative to the different rehabilitation solutions provides valuable information for future emergency recovery of similar structures.
APPROACH (100 words or fewer)	1. Select and collect information of target buildings (~9) in different condition 2. Create detailed structural building models in SAP and ANSYS 3. Reproduce shear wall failures using inelastic dynamic analysis 4. Introduce recovery sequence in structural model 5. Evaluate different retrofit and strengthening techniques for the damaged building structures 6. Incorporate energy dissipation and evaluate response 7. Compute predicted building response with proposed recovery sequence 8. Monitor site implementation of building recovery
ESTIMATED COST	1 + 2 + 3~ \$70,000 4 + 5 + 6 + 7~ \$70,000 8 ~ \$50,000
TIMELINE	1 + 2 + 3 ~ 12 months 4 + 5 + 6 + 7 + 8 ~ 12 months
DISCUSSION COMMENTS:	US engineers commented that given a particular building, a repair strategy could likely be determined quickly. Several Chilean engineers commented that there were many buildings damaged, and that a more general approach to repair was needed, and that engineers lacked confidence in whether some methods would work (e.g., they were related to current code provisions that produced problematic behavior). Mahin commented that a similar situation developed in the Wenchuan earthquake due to the large number of damaged buildings, and the lack of clear guidelines to identify appropriate repair strategies, and trained engineers to work on a large number of buildings.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 14:	Study of the building collapse
PROPONENT:	Jack Moehle (UC Berkeley)
REASON STATEMENT: (100 words or fewer)	One significant engineered building collapsed completely during the earthquake. Drawings and ground motion data are available to study this building. A focused study should investigate whether this collapse could have been predicted using the most advanced computer analyses, whether it might have been anticipated by code-based analysis, and generally what were the characteristics that contributed to collapse.
APPROACH (100 words or fewer)	Collect detailed data on the building collapse. Use structural drawings to construct an analytical model of the building. Conduct studies to understand the parameters that contributed to collapse and whether they could have been anticipated in design.
ESTIMATED COST	$100,000
TIMELINE	18 months
DISCUSSION COMMENTS:	Thought useful to study buildings that collapsed or were near collapsed so we can assess ASCE 41 or other approaches for evaluating existing structures.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 15:	Axial stress limit for special structural walls
PROPONENT:	Jack Moehle (UC Berkeley)
REASON STATEMENT: (100 words or fewer)	Walls confined by ACI 318 special boundary elements are expected to exhibit ductile flexural behavior. However, this expectation might not be realized for walls with high axial loads. The 1997 UBC placed an upper limit of 0.35Agf'c on walls considered part of the seismic-force-resisting system. That limit was never included in ACI 318 or in the IBC. In some buildings in Chile, walls were designed with high axial stresses, which may have contributed to failures. A study should examine whether adding an axial stress limit to ACI 318 would be prudent.
APPROACH (100 words or fewer)	(a) Conduct basic analytical studies of expected flexural response of walls varying axial stresses, longitudinal reinforcement, confinement reinforcement, and wall thickness (which affects ratio of cover to core dimensions). (b) Collect data on design and performance of selected Chilean buildings, working with Chilean engineers. Evaluate whether axial stress was a factor in behavior of wall buildings. (c) Recommend code changes if appropriate.
ESTIMATED COST	$100,000
TIMELINE	18 months
DISCUSSION COMMENTS:	Bonelli commented that this might be related to the location of the neutral axis (and thus strain demands in longitudinal bars). It was agreed that this was an important topic to resolve quickly.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 16:	Collapse Prediction of Wall Structures
PROPONENT:	R. Hamburger (SG&H)
REASON STATEMENT: (100 words or fewer)	Current procedures embodied in ASCE 31 and 41 for predicting "collapse prevention" performance appear to be grossly conservative when applied to mid-and high-rise buildings of the type common in Chile. Many of these buildings sustained far more damage to walls than would be permitted under the aforementioned standards for "collapse prevention" performance, yet still met the qualitative goals for this performance level. The result is that resources are needlessly expended to upgrade buildings beyond the level required to actually achieve the desired performance and as a result, fewer buildings are retrofit than may otherwise be possible or desirable.
APPROACH (100 words or fewer)	Select a few heavily damaged wall buildings, for example, Edificio Toledo or Edifico Torre Del Mar and attempt to simulate their behavior as actually observed in order to develop more confident analysis guidelines for wall structures.
ESTIMATED COST	$250,000
TIMELINE	1 year
DISCUSSION COMMENTS:	Similar to 14, but with emphasis on buildings in the near collapse state.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 17:	Vertical distribution of seismic design forces
PROPONENT:	R.O. Hamburger (SG&H)
REASON STATEMENT: (100 words or fewer)	The Uniform Building Code and codes based on its seismic provisions used a linear vertical distribution with an additional “top force, F_T” applied at the top diaphragm, for buildings with periods in excess of 0.7 seconds. More recent codes based on ATC3-06 have replaced this vertical distribution with an exponential formulation that results in reduced design force at upper stories. The ASCE team observed numerous mid-rise buildings with significant shear damage to walls in the upper stories.
APPROACH (100 words or fewer)	Perform a survey of extent of damage to walls in selected buildings and compare alternative vertical distribution approaches, including response spectrum analysis methods to evaluate demands upper story walls, and probably performance given alternative design approaches./
ESTIMATED COST	$50,000
TIMELINE	6 months
DISCUSSION COMMENTS:	This seemed to be a common observation, but many noted that damage also concentrated at the bottom of the building. In either case, it was not uniform, suggesting design force distributions are not creating a uniform demand/capacity ratio over height. Bonelli noted recent work by Restrepo and others related to importance of second mode response on tall buildings with the possibility of forming a second plastic hinge in the upper regions of the wall, and the role of capacity design in the design of tall walls. Hooper and others indicate that the forces developed in walls are very sensitive to the capacities provided, and by making walls stronger, the demands can increase.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 18:	Performance goals for residential buildings
PROPONENT:	R.O. Hamburger (SG&H)
REASON STATEMENT: (100 words or fewer)	U.S. building codes incorporate performance goals of substantial anticipated damage for design-level or more severe earthquakes. The Chile earthquake demonstrates that even though such design approaches are effective in minimizing casualties, they can result in substantial loss of housing. This can have long term, destabilizing socializing and economic effects in a region.
APPROACH (100 words or fewer)	Develop alternative designs for a series of prototype mid and high rise structures using alternative criteria and perform evaluations to determine probable performance for design and MCE level events. Based on these studies, develop a assessments of housing loss in typical communities, for example San Francisco or Los Angeles, and develop cost-benefit models to evaluate appropriate performance goals
ESTIMATED COST	$1,000,000
TIMELINE	3 years
DISCUSSION COMMENTS:	The effect of a significant loss of occupancy, or having to demolish a tall building in an urban area was noted by several participants to be an important problem.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 19:	Study minimum dimension of confined cores within shear walls
PROPONENT:	Jim Harris (J.R. Harris & Co)
REASON STATEMENT: (100 words or fewer)	Many walls with thickness on the order of 8 inches showed significant crush zones within the plastic hinge zones. The failure phenomena may be related to the inability to effectively confine a small concrete core with conventional sizes of rebar.
APPROACH (100 words or fewer)	A review of past testing of scaled model followed by a combination of analytical modeling and laboratory testing for validation.
ESTIMATED COST	TBD – depends on nature of laboratory work involved
TIMELINE	1 to 2 years
DISCUSSION COMMENTS:	Several others noted importance of same topic.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 20:	Compare variation building code design objectives with variation in seismic ground shaking hazard
PROPONENT:	Jim Harris (J.R. Harris & Co)
REASON STATEMENT: (100 words or fewer)	Our design objective for ordinary buildings has recently been quantified to be approximately a 1% risk of collapse in a 50-year period. This has replaced the qualitative objective long stated in the SEAOC Blue Book. It has acceptance based upon comparison to traditional values in San Francisco. The actual performance in Chile and the high frequency of earthquakes there give us an opportunity to test this objective and propose alternatives.
APPROACH (100 words or fewer)	Introduce monetary damage functions with meaningful time/value relations to expand the ATC 63 methodology.
ESTIMATED COST	TBD; it will require a seismological input on the Chilean ground motion hazard, and might be divided into phases.
TIMELINE	Less time critical than other proposed topics; desirable to finish within 3 years.
DISCUSSION COMMENTS:	None

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 21:	Compare drift limits in Chilean and US practice and assess the effect of the differences
PROPONENT:	Jim Harris (J.R. Harris & Co)
REASON STATEMENT: (100 words or fewer)	Chilean engineers traditionally skipped US requirement for confinement of ends of shear walls due to low limits on shear stress and on building drift. The shear stress differences are not significant in the current codes, but the drift limits are. The effect on nonstructural damage may be significant.
APPROACH (100 words or fewer)	(1) Quantitative comparison of the codes based upon simple analysis of several prototypical buildings. (2) Gather statistics (from others) on value of structural and nonstructural damage in 2010 Chile EQ and recent US earthquakes. (3) Develop correlations where they exist.
ESTIMATED COST	Item (1) will be minor – say $10,000 to $20,000. Item (2) should build upon the work of others – budget to be developed. Item (3) is a guess at $50,000
TIMELINE	6 to 12 months
DISCUSSION COMMENTS:	No comment.

Table D.2 Detailed Descriptions of Suggested Study Topics (Continued)

TOPIC NO. 22:	Effect of Co-Seismic Ground Displacement on Building Performance
PROPONENT:	Farzad Naeim (JAMA)
REASON STATEMENT: (100 words or fewer)	GPS instrumentation indicates maximum ground displacements in excess of about 3m (10 feet) occurring in about 25 seconds in Concepcion. What was the impact of such large displacements on performance of tall buildings in Concepcion? How tall building design should be modified if necessary to address such large displacements
APPROACH (100 words or fewer)	Subject analytical models to ground displacements (not accelerations) of this type and study the results
ESTIMATED COST	$50,000 to $100,000
TIMELINE	1 year
DISCUSSION COMMENTS:	Mahin noted that similar studies were made following 1999 Chi Chi earthquake where 10 meter displacements were observed. However, the long duration of this event may have different effect than seen in Taiwan.