Applied Technology Council
A Nonprofit Corporation
Advancing Engineering Applications for Hazard Mitigation
California • Delaware • Virginia

201 REDWOOD SHORES PARKWAY, SUITE 240 REDWOOD CITY, CALIFORNIA 94065
PHONE 650/595-1542 FAX 650/593-2320 WEB SITE www.atcouncil.org

FEMA/ATC Project to Evaluate the Earthquake Collapse Potential of Older Concrete Buildings and How It Could Be Used

What are nonductile concrete buildings and why are they a risk to the public?

Nonductile concrete buildings are concrete frame or wall buildings that were constructed prior to the mid-1970s, and include archaic construction dating back to the early 1900s. The primary problem with this type of construction was insufficient transverse reinforcing steel within the concrete columns, which does not provide adequate confinement to the concrete or shear strength for the column, both of which cause non-ductile failure modes. Other deficiencies often present include overall lateral weakness and structural irregularities, both of which can also lead to collapse.

This problem came to the fore in the 1971 San Fernando, California, earthquake, when several of these buildings, including a Veteran's Administration Hospital, collapsed with loss of life, and several, including the brand new Olive View Hospital, nearly collapsed. Shortly after that event, building codes and standards were modified to correct these deficiencies. Concrete buildings constructed since the late 1970's are assumed to provide adequate collapse prevention in earthquakes.

The seismic risk presented by these older existing nonductile concrete buildings remains a significant concern as many of these buildings are of significant size and occupancy load. While most of these buildings should be expected to suffer severe damage in strong ground shaking, not all of them are collapse hazards. This complexity is caused by the fact that this class of construction includes a wide variety of structural details and configurations, not all of which are high-risk.

Retrofitting criteria have been in place for mitigating nonconforming concrete buildings for many years; however, the problem remains one of identifying which buildings within a larger inventory of existing buildings pose a high risk for collapse. Because of the complex nature of the problem, it is nearly impossible to visually determine which of these buildings would be collapse hazards and which would not.

What can a community do to address the risk presented by nonductile concrete buildings?

There are several steps that a community can undertake to address the risk presented by non-ductile concrete buildings.

A first step would be to develop an inventory of older concrete buildings; those built before 1980. This has been undertaken by different groups in different communities. The most notable example to date is the list of nonductile buildings developed for the City of Los Angeles as part of the National Science Foundation (NSF)-funded NEES[1] Grand Challenge Project, "Mitigation of Collapse Risks in Older Reinforced Concrete Buildings", Jack P. Moehle, Principal Investigator, University of California at Berkeley. That list, which was released to the public as part of the Northridge20 Symposium on January 16-17, 2014 in Los Angeles, contains over 1500 individual buildings. Other examples are the estimated inventories of the number of these buildings created by the Concrete Coalition[2] for several California communities.

Development of such an inventory should begin with examining data bases that may include basic information, such as building permit files, tax assessor files, and Sanborn maps. Once an initial list has been prepared from this data or if such data are not available, a sidewalk survey can then be undertaken to verify and expand the list. This can often be done using volunteer architects and engineers, others with technical experience (such as building inspectors and firefighters), and/or students in these fields. Such an inventory provides the overall universe of buildings where further study can then be focused. However, care is needed as sidewalk surveys can miss or incorrectly identify buildings as pre-1980 reinforced concrete buildings.

A second step would be to perform an initial examination of all of the non-ductile concrete buildings within the inventory to identify certain characteristics that may be indicative of a high seismic risk non-ductile concrete building. These characteristics may include:

- A first story where the story height is significantly higher than the remaining stories yet there appears to be no indication of stronger construction to address this deficiency, such as stockier or more numerous first floor columns.
- A first story where most of the first floor contains a significant percentage of openings, such as display windows or entrances, while the floors above are mostly walls.
- The age of the building; was it designed to a code that pre-dated the 1976 *Uniform Building Code*.
- Less than the usual number of walls present in the building.
- Other significant vertical irregularities, such as a story with a significant change in wall configuration or story height.
- A significant horizontal irregularity, either from a non-rectangular shape or non-symmetrical frames or walls that would cause significant torsion.

These indicators in and of themselves are not proof that a building is a high seismic risk non-ductile concrete structure, but may be indicators of which buildings should be given a higher priority when evaluations are performed in the next step. However, to be effective, this initial

[1]NEES: The George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES) **encompasses management headquarters, 14 earthquake engineering and tsunami research facility sites, and a cyber infrastructure platform (the NEEShub) located at universities across the United States. NEES enables collaborative research on the nation's most pressing problems in earthquake hazard reduction.**

[2] The Concrete Coalition is a network of individuals, governments, institutions, and agencies with a shared interest in assessing the risk associated with non-ductile concrete buildings and developing strategies with which to mitigate that risk. The Coalition is a program of the Earthquake Engineering Research Institute (EERI), the Pacific Earthquake Engineering Center (PEER) at the University of California at Berkeley, the Applied Technology Council (ATC) and their partners, including the Structural Engineers Association of California, The American Concrete Institute, Building Owners and Managers Association (BOMA) of Greater Los Angeles and the U.S. Geological Survey. While not officially part of the Coalition, funding is also indirectly provided by the FEMA.

review should really be performed by an engineer who has access to the original building drawings.

Much of the information that would help determine if a building is a high seismic risk from collapse could be obtained by a relatively simple questionnaire. These questions would include:

- Date of construction.
    - Was the building designed to 1976 UBC or later?
- Has the building been retrofitted? If so, when and to what criteria?
- Are the vertical gravity elements of a material other than concrete (lift slabs excepted)?
- Number of stories from the base.
- Number of stories below the base.
- Total area (or non-garage occupied area).
- Concrete wall area as a percent of floor area (every floor).
- Brick infill wall area as a percent of floor area (every floor).
- Primary floor system: flat plate, two way slab, waffle, one way slab/beam, one way joist/girder, other.
- Primary vertical gravity system: concrete columns or concrete walls, other.
- Columns appear to be part of the lateral force resisting system: tie type: spiral, lapped, 90 degree hooks, 135 degree hooks, typical spacing.
- Columns apparently designed only for gravity: tie type similar to previous?
- Is there any apparent weak story?
- Is there a severe torsional irregularity?

A third step would be to prioritize the list of older concrete buildings, based on the assumed risk. This would include higher risk structures based on the results of the second step and would also consider critical facilities such as a hospital or emergency operations center. It would also consider high or important occupancy facilities, such as schools.

A fourth step would then be to begin assessing each structure based on the above priority ranking to determine if it is indeed a collapse prone concrete building. Such assessments require an engineering evaluation using original building drawings and intensive calculations. Currently, the only methods available are the American Society of Civil Engineers (ASCE) / Structural Engineering Institute (SEI) Standards on *Seismic Evaluation of Existing Buildings* (ASCE/SEI 31) and *Seismic Retrofit of Existing Buildings* (ASCE/SEI 41).

ASCE/SEI 31 has a simplified Tier 1 method that could be used as a first cut, and this procedure can be done for roughly $5,000 to $10,000 per building. However, as is usually the case with simplified procedures, this method is so conservative that the majority of buildings will be found to be high seismic risks and further evaluation would still be required. Given the numbers of buildings that would not pass the ASCE/SEI 31 Tier 1 evaluation, an argument could be made that using this method may not be cost effective. The more extensive methods found in ASCE/SEI 31 and ASCE/SEI 41 require far more rigorous evaluations, using non-linear analysis (such as an incremental dynamic analysis) that are time consuming and expensive. These procedures can cost as much as $50,000 per building. What is missing is a middle step, something more discriminating than a Tier 1 evaluation but not as costly as a full ASCE/SEI 31 or ASCE/SEI 41 evaluation.

Is it possible to develop a local ordinance to address this risk, and what would it look like?

If a community has the political will and the incentive to develop and adopt a local ordinance to address the risk presented by nonductile concrete buildings, either through some form of voluntary or mandatory ordinance, there are several paths that could be taken. These options would basically mirror the steps described above. One of the most acceptable and easily passed ordinance would be one that would ultimately develop an inventory of older concrete buildings. Such an ordinance would require some form of self-reporting similar to the first step of the recently passed San Francisco Weak Story ordinance. Here, building owners, based on an initial list, would be required to have a report prepared documenting whether their building fit within the criteria of a nonductile concrete building. In some cases, like the City of Los Angeles, this inventory has already been prepared and, while it may not be perfect, it is good enough to move to the next step.

If an inventory has already been prepared, such as for Los Angeles by the NEES Grand Challenge Project or for other communities by the Concrete Coalition, then the next possible ordinance step would be to require that owners of the buildings listed in the inventory prepare a report documenting the specific characteristics of their building, so that a determination could be made as to whether or not their building is a non-ductile concrete building. These characteristics would be used as input by the jurisdiction for developing priorities if a staggered time line was desired.

The next step of a possible ordinance would be to require building owners to conduct such an engineering evaluation to determine the collapse risk of their nonductile concrete building. As indicated above, this requirement could be staggered, depending on occupancy or suspected seismic deficiencies from the information previously submitted. Since it is currently an expensive process to make such a determination, this would be a difficult ordinance to get passed.

The final and by far most difficult ordinance step would be mandate that buildings found to be high seismic risk of collapse be retrofitted to ASCE 41 or a similar specified level of improved risk to prevent the building from collapsing in an earthquake.

What is the FEMA/ATC Older Concrete Buildings Project?

The multi-phased ATC-78 project series is currently being performed by the Applied Technology Council (ATC), under contract to FEMA, to develop a new evaluation methodology that will more easily and accurately predict the seismic collapse potential of older non-ductile frame and wall buildings. The methodology uses a simplified linear analysis approach with nonlinear modifiers to estimate nonlinear analysis deformations. The goal of this project is to develop an assessment guideline document for older non-ductile concrete buildings to allow identification of those buildings that present a high risk seismic collapse hazard.

Work on this project series is closely coordinated with: the above-described NSF-funded NEES Grand Challenge research project, "Mitigation of Collapse Risks in Older Reinforced Concrete Buildings"; a National Institute of Standards and Technology (NIST)-funded project to "Develop

Collapse Indicator Methodology for Existing Reinforced Concrete Buildings" (ATC-95 Project); and EERI's Concrete Coalition.

The final product of the ATC-78 project series will be titled "*Seismic Evaluation for Collapse Potential of Older Concrete Buildings*" and identified as FEMA P-1000. It is being developed to provide a more accurate assessment than an ASCE/SEI 31 Tier 1 evaluation but at a lower cost than a full ASCE/SEI 31 or ASCE/SEI 41 evaluation. We currently estimate that an average evaluation using FEMA P-1000 would cost $15,000 or less.

What is the current status of the FEMA/ATC Older Concrete Buildings Project?

The evaluation methodology for concrete frame structures has been in development for two years and is approximately 80 percent complete. The development of evaluation methodology for wall structures is just beginning and is less than 20 percent complete. Work this year in the ATC-78 project series is focusing on finalizing the draft frame evaluation methodology and continuing development of the wall evaluation methodology. Some initial validation work on the frame evaluation methodology is currently being conducted, but a formal testing and validation program is not scheduled until next year. This year's FEMA funding for this project is $350,000. While this amount is sufficient for developmental work, it is not enough to perform all of the required work as quickly as it could be done.

Can the ATC 78/FEMA P-1000 draft document be used this year to perform an analysis?

The concrete frame building evaluation methodology is to the point where it could be subjected to a controlled validation study. However, current project funding is not sufficient to begin such an effort this year. It may be possible to conduct a limited number of evaluations as part of a controlled validation study if funding were made available. However, since the document and frame methodology are still in draft form and have not been validated, this could only be done in a controlled environment and only by project personnel or other designated qualified engineers. While some interest has been expressed by the City of Los Angeles and the State of California to conduct such studies on a portion of the 1,500 Los Angeles buildings identified in the NEES Grand Challenge Project, there are presently no plans to do so.