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CAL VIVA: ASSESSING THE SEISMIC VULNERABILITY OF CALIFORNIA'S STATE-OWNED BUILDINGS THROUGH PLANNING & ENGINEERING

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ABSTRACT

The California Vital Infrastructure Vulnerability Assessment (Cal VIVA) project, undertaken by engineering and planning faculty at California Polytechnic State University-San Luis Obispo (Cal Poly) in support of the California Governor's Office of Emergency Services (Cal OES), has established an approach to identify and mitigate seismically vulnerable state-owned buildings. The Cal VIVA project developed a standardized screening and earthquake vulnerability assessment methodology using industry standards. Due to the large number of state-owned buildings, the Cal VIVA project focused on buildings identified as critically necessary for response and recovery efforts. Cal VIVA concluded that the most direct institutional knowledge about physical characteristics of individual buildings resides with state agencies and departments, and there is a greater likelihood for successful implementation of Cal VIVA methodology if building assessments focus at the department level, rather than at the statewide level. Based on this conclusion, the Cal VIVA project developed and tested a template which individual state departments can use to systematically address critical building vulnerability and to implement potential mitigation measures on a long-term basis. The project also developed a State Reporting Plan to facilitate planning and monitoring the statewide progress of seismic vulnerability mitigation.

The intended outcome of the Cal VIVA project is implementation of a statewide coordinated plan to reduce seismic vulnerability and increase natural hazard resiliency of state-owned buildings.

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Introduction

The California Vital Infrastructure Vulnerability Assessment (Cal VIVA) Project is a hazard-mitigation project funded by National Earthquake Hazard Reduction Program (NEHRP) through the Federal Emergency Management Agency (FEMA) and sponsored by the California Governor's Office of Emergency Services (Cal OES). Cal VIVA is an implementation element of the 2013 California State Multi-Hazard Mitigation Plan, also known as the State Hazard Mitigation Plan (SHMP). The purpose of the SHMP is to significantly reduce deaths, injuries, and other disaster losses due to natural hazards in California.

The 2013 SHMP describes past and current hazard mitigation activities and outlines goals, strategies, and actions for reducing future disaster losses. It emphasizes that California's resiliency (ability to survive and recover from a disaster) strongly depends on the state's capacity to maintain or restore operations of its infrastructure, including state-owned buildings, and that systematically assessing the condition of infrastructure is an important step toward mitigation.

The goal of the Cal VIVA project is to systematically identify state-owned buildings that are vulnerable to natural hazards and pursue mitigation measures which protect their resilience and functionality, thereby reducing disaster losses, enhancing response, and facilitating recovery. Currently Cal VIVA is focused on the seismic vulnerability of state-owned buildings vital to response and recovery operations.

The Cal VIVA project was composed of three phases: Cal VIVA I: Upgrading Critical Facilities; Cal VIVA II: The Next Steps; and Cal VIVA III: Mitigation and Reporting Plans. This paper summarizes the findings of all three phases. The first two phases (Cal VIVA I and Cal VIVA II) were completed in March 2013; the third phase (Cal VIVA III) was completed in November 2013.

The Cal VIVA I project began with the acknowledgment of the extraordinary challenge of determining seismic vulnerability for over 24,000 state-owned buildings. Cal VIVA I first focused on the development of a standardized screening approach and an earthquake vulnerability assessment methodology for individual state-owned buildings identified as critically necessary for response and recovery operations. This screening approach/methodology was tested on 19 buildings from four departments: Department of Forestry and Fire Protection (CAL FIRE), California Highway Patrol (CHP), California Department of Transportation (Caltrans), and California Department of Water Resources (DWR). For these selected facilities, the project made recommendations and developed associated costs for mitigating structural and nonstructural seismic vulnerabilities. Cal VIVA I concluded that the most direct institutional knowledge about physical characteristics of individual buildings resided with state agencies and departments, and there was a greater likelihood for successful implementation of the Cal VIVA methodology if building assessments focused at the department level rather than at the state level.

The underlying approach for Cal VIVA II and Cal VIVA III was established from these conclusions. Using the methodology developed in Cal VIVA I for assessing and mitigating

seismic vulnerability of individual buildings, Cal VIVA II developed and tested a framework for a Department Seismic Mitigation Plan, which created a systematic departmental approach to reducing that department's seismic vulnerability for its critical buildings. One outcome of Cal VIVA II was the determination of a need to create a statewide reporting system to better understand and mitigate the seismic vulnerability of state-owned buildings critical to respond and recover efforts after an earthquake.

Cal VIVA III refined the Department Seismic Mitigation Plan framework. A template was created and tested to assist departments in the development of their individual plans. Cal VIVA III also addressed the need to develop a statewide inventory by proposing the establishment of a state-managed repository for building assessment information, known as the State Reporting Plan. Through the State Reporting Plan, necessary seismic mitigation actions for state-owned buildings can be systematically identified, implemented, and monitored.

Cal VIVA Department Seismic Mitigation Plan

The Cal VIVA Department Seismic Mitigation Plan outlines a systematic approach that a department can undertake to assess its building stock's seismic vulnerabilities and prioritize improvements to that inventory. Since the numerous State entities owning building stock vary in mission, size, and access to engineering knowledge, this plan defines a general approach that can be tailored to an individual need. Application of this approach results in an action plan that clearly defines the extent of a department's building assets' seismic vulnerabilities, prioritizes needed retrofit improvements, and identifies costs and associated construction funding.

The following five main process steps define the Department Seismic Mitigation Plan:

1. **Vital Facility Screening.** Develop a listing of state-owned buildings that are critically necessary for post-earthquake response and recovery operations by a department.
2. **Site Seismicity & Vulnerability Screening.** Screen vital buildings to identify those that are potentially seismically vulnerable.
3. **Building Seismic Assessment & Mitigation.** Assess identified buildings to determine the extent of their seismic vulnerability, and, as necessary, develop a retrofit scheme and determine an associated construction cost.
4. **Department Seismic Mitigation Plan.** Develop a department-wide seismically vulnerable buildings hazard mitigation plan.
5. **State Reporting Plan.** Report summary data to Cal OES for progress monitoring as defined in the State Reporting Plan.

These five process steps are described and elaborated in greater detail in the graphical flowchart, Fig. 1 Cal VIVA Department Seismic Mitigation Plan, shown on the following page. Although the Cal VIVA methodology is conceptually simple to apply, much of its complexity lies in obtaining the necessary data from which to make informed decisions. Identification of vital buildings is an ongoing process for many of the departments due to changing emergency response responsibilities. Construction data for the individual buildings is often difficult to locate and, in some cases, not obtainable. As the five process step requirements are further defined, suggestions are included to control complexity by minimizing some of these data collection

requirements. The following sections better define the process steps and tasks necessary to create a Department Seismic Mitigation Plan.

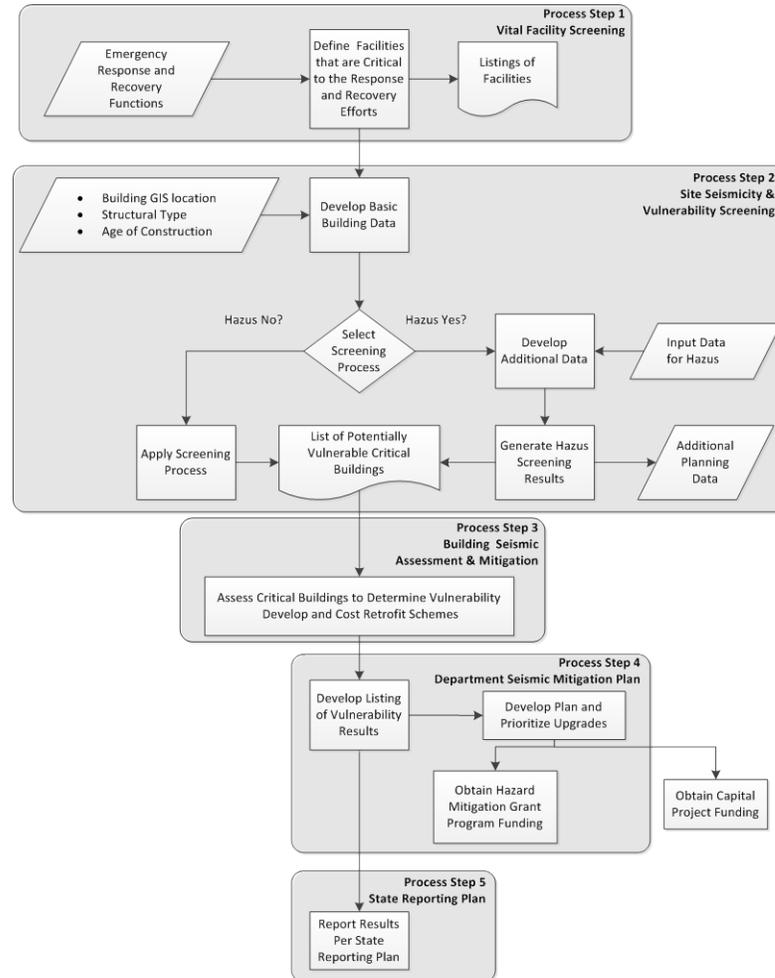


Figure 1. Cal VIVA Seismic Mitigation Department Plan

Process Step 1: Vital Facility Screening

Process Step 1 is an application of the first Cal VIVA trigger – *functionality* – that captures the building’s function in the response and recovery effort. The vital buildings are defined by examining each department’s responsibilities and functions after an earthquake. Once the functions are defined, the department can identify buildings that house those vital functions and must be *operational* after an earthquake. Cal VIVA identifies *operational* as having a performance objective of Immediate Occupancy. A performance objective combines a desired performance level with a specified earthquake hazard. *ASCE 31-03 Seismic Evaluation of Existing Buildings*³ (ASCE 31-03) defines Immediate Occupancy performance as building

³ *ASCE 31-03. Seismic Evaluation of Existing Buildings*. Reston VA: American Society of Civil Engineers: 2003.

performance with damage to both structural and nonstructural components during a design earthquake such that: (a) the damage is not life-threatening, so as to permit immediate occupancy of the building after a design earthquake, and (b) the damage is repairable while the building is occupied.

Process Step 2: Site Seismicity & Vulnerability Screening

Process Step 2 is the application of the two remaining Cal VIVA triggers: Trigger 2 – *site seismicity* – which is a measure of the earthquake’s forces delivered to the building, and Trigger 3 – *building vulnerability* – that defines the ability of that specific building to survive the earthquake.

Trigger 2 – *site seismicity* – is a measure of the ground’s ability to deliver earthquake forces to a building. The US Geologic Survey (USGS), working with the California Geologic Survey (CGS), has developed an extensive database on the potential for ground shaking due to earthquakes. This information is based on Geographical Information Systems (GIS), simplifying the development of ground shaking at any specific site. Once the building is determined to be vital and its address is known, the specific latitude and longitude can be obtained and the susceptibility of the ground shaking can be calculated.

Buildings are considered to be potentially seismically vulnerable when they are located in geographic areas known to have high seismicity as defined by ASCE 31-03. (Note: ASCE 31-03 is in the process of being updated and combined with *ASCE 41-06 Seismic Rehabilitation of Existing Structures*. Specific references should be verified when *ASCE/SEI 41-13 Seismic Evaluation and Retrofit of Existing Buildings* takes effect.)

Trigger 3 – *building vulnerability* – defines the ability of that specific building to survive the earthquake so as to be able to fulfill the functional requirement. This capability is determined largely by its structural system type, configuration, and structural building code provisions under which it was designed. The structural system type refers to those primary elements within the building that resist the earthquake’s forces. Examples of common structural systems are wood shear wall systems with flexible diaphragms or steel-braced frame systems with rigid diaphragms. The difficulty in determining the structural type often makes the third trigger the most challenging one.

Much of the information required for this trigger is easily obtained if the original construction drawings are available for review by an engineer or trained staff. Some departments, such as Department of Water Resources, have maintained an extensive archive of the construction documents for its structures. Other departments may have difficulty locating those documents. The Department of General Services (DGS) maintains a construction document archive of buildings with which it has been associated. Unfortunately, the maintenance of that archive has not been funded for many years, and the archive is incomplete and difficult to negotiate. For the Cal VIVA project, the team assessed eight California Highway Patrol (CHP) area offices. The DGS archive and the CHP archive yielded drawings for many, but not all, of the eight buildings.

It is relatively common not to have access to construction documents. A systematic approach to determining structural type has been developed and is documented in the 2002 Second Edition of *FEMA 154 Rapid Visual Screening of Buildings for Potential Seismic Hazards*⁴. (Note: FEMA 154 is a rapid-screening method that identifies potentially seismically vulnerable buildings for more detailed assessments. Its focus is on *life-safe* buildings, unlike those buildings identified in Process Step 1 that are vital to a department's response and recovery efforts, and thus use of FEMA 154 is not recommended without modifications. The Applied Technology Council is in the process of updating this document.)

Process Steps 1 and 2 present a reasonable screening approach to determine which buildings are potentially vulnerable. The Cal VIVA team experimented with the use of Hazus⁵ as an alternate screening method in a pilot study using the California Highway Patrol's area offices. The study showed promise provided that the typical building types available in Hazus are a reasonable match for the physical buildings owned by the department. Like Process Steps 1 and 2, at the conclusion of the Hazus screening, the department will have developed a list of buildings to assess for potential seismic vulnerabilities. In addition, since Hazus can generate a large amount of additional data for use in mitigation planning, its use is suggested for those departments with an interest in this advance planning information.

Process Step 3 – Building Seismic Assessment & Mitigation

Process Step 3 requires that individual vital buildings identified as potentially vulnerable in Process Steps 1 and 2 be assessed for seismic vulnerabilities and where needed seismic retrofit schemes be developed with associated costs. Although each building is unique and faces special challenges, it is necessary to apply a systematic approach to the building inventory so that comparisons between building vulnerabilities can be made and prioritization of retrofits can be established. The ASCE 31-03 standard is recognized throughout the United States as a reasonable and logical approach to determining the vulnerabilities of existing buildings. Due to its simplicity and national acceptance, the method as defined in ASCE 31-03 was selected to be the most suitable for the Cal VIVA process.

ASCE 31-03 is a three-tier assessment process, with each subsequent tier requiring more advanced analysis. The testing of the Cal VIVA methodology used either a Tier 1 or a Tier 2 Evaluation. The Tier 1 Evaluation is conservative and relatively simple to apply. It utilizes a series of building checklists and simple engineering calculations. If a building "passes" Tier 1, experience has shown that it is very likely that the building's behavior in an earthquake will be adequate. Tier 2 requires additional engineering analysis to investigate building behavior. It is common to use results of the Tier 1 or Tier 2 Evaluation coupled with engineering judgment to determine if a seismic retrofit is needed.

Tier 1 Evaluations are to be performed on all vital buildings thought to be seismically vulnerable by utilizing a series of checklists and supporting analysis. The three types of

⁴ FEMA P-154. Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook. Second Edition. FEMA Library. FEMA 2002. Web. 22 Jan. 2013.

⁵ Hazus, developed for FEMA, is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes using GIS technology.

checklists: structural, non-structural, and geologic site hazard and foundation, were developed based on historical observations of areas of poor performance and damage in thousands of buildings. The geologic site hazard and foundation checklist identifies hazards, such as adjacency to ground faults, liquefaction, and other hazards, that should also be addressed as part of the assessment process.

The number of potentially seismically vulnerable vital buildings is expected to vary from department to department. Departments with a small number of identified buildings may choose to perform seismic assessments on all their buildings. For departments with a large number of identified buildings, developing an order for the assessments can optimize the process. Ordering can be based on the age of the buildings, structural building types, building criticality, or a criterion specific to that department. A benefit of selective ordering was observed during the Cal VIVA seismic assessments. California Highway Patrol (CHP) and Department of Water Resources (DWR) had multiple buildings with similar structural types and ages. The Cal VIVA team ordered those departments' assessments based on a representative sample of the various building types. At the conclusion of the sampling assessments for CHP, a number of seismic vulnerabilities were observed in one specific building type leading to a focus in that area.

Seismic retrofitting, as a mitigation measure, may be required to improve the performance of seismically vulnerable buildings. The decisions related to structural retrofits require planning with owners, planners, contractors, and engineers. The planning, design, and construction of seismic retrofit projects can be complex due to a variety of factors, which fall into three basic factors: 1) if the building will be occupied during construction, 2) if additional non-seismic upgrade requirements will be triggered, and 3) if the owner elects to implement additional improvements. As a result of these three factors, it is unusual to have a project that only seismically retrofits a building. This makes planning and budgeting for the project at a conceptual level extremely difficult.

The chosen retrofit should be based on common engineering concepts. All seismic conceptual retrofit design should meet the intent of *ASCE 41-06 Seismic Rehabilitation of Existing Structures* (ASCE 41-06)⁶ and the current California Building Code. The rationale for this approach is to develop a budgetary cost number that could be used by departments for early planning purposes and to allow for comparison between building projects. Additional engineering is likely required prior to obtaining funding for any specific project giving an opportunity to optimize the retrofit approach at that time.

Testing of the Department Seismic Mitigation Plan Approach Process Steps 1, 2, and 3

The usability of the Cal VIVA Department Seismic Mitigation Plan concept and template (Process Steps 1, 2, and 3) were tested with the assistance of the Caltrans during Cal VIVA II and DWR during Cal VIVA III. Both tests proved that the Cal VIVA methodology could be successfully applied by a department. However, the tests also demonstrated that the process requires significant staff time and department resources. Although Cal Poly faculty assembled much of the documentation and performed the seismic assessments, the development of those portions of the department plan detailed in Process Steps 1, 2, and 3 still required significant

⁶ *ASCE 41-06. Seismic Evaluation of Existing Structures*. Reston VA: American Society of Civil Engineers: 2006.

department staff time in areas such as information gathering, interviews, reviews, and policy decisions. Process Steps 4 and 5 involve significant policy decisions and knowledge of future capital plans and financial resources, and therefore is likely to require senior staff participation.

Process Step 4 – Department Seismic Mitigation Plan

Process Step 4 is the preparation of Department Seismic Mitigation Plans, consisting of summaries of the building seismic screening, individual building seismic assessment and mitigations, building mitigation prioritization, potential mitigation funding sources, and a mitigation schedule. Each department's plan will vary based on its mission and priorities. As an example, the results of 19 building assessments performed to test the Cal VIVA I approach were given to the four departments (Caltrans, CAL FIRE, CHP, and DWR). The departments acted on this knowledge in different ways. Caltrans relocated vital functions to less vulnerable buildings. CHP accelerated planning for vital building replacement since the vulnerable buildings were inadequate to house needed staff.

Currently, each department is responsible for securing funding for its own building improvements. The most promising potential funding sources for the seismic upgrade of state-owned buildings are either FEMA hazard mitigation grants or capital program funding by an individual agency or department.

Process Step 5 – State Reporting Plan

Process Step 5 is the transmission of summary findings to California Governor's Office of Emergency Services for State Hazard Mitigation Plan Updates and Progress Monitoring using a system referred to as the State Reporting Plan. Through this plan, necessary seismic mitigation actions for state-owned buildings can be identified, implemented, and monitored.

State Reporting Plan

As the work on Cal VIVA continued, there was recognition by the team of a need to develop a statewide inventory of the seismically vulnerable state-owned buildings so that the State's overall vulnerability can be understood and mitigated over time.

The seismic vulnerability of state-owned buildings has been a concern for many years. In 1990, California voters passed the Earthquake Safety and Public Buildings Rehabilitation Bond Act of 1990 (Proposition 122), which mitigated the seismic vulnerabilities of more than 55 structures and performed preliminary vulnerability assessment on more than 9,000 buildings. In addition, many State entities have created their own seismic programs, such as the University of California with ten campuses, the California State University with 23 campuses, and the Administrative Office of the Courts. Since these efforts were undertaken by individual departments or agencies and the one isolated bond effort, there was no statewide reporting of this work. In addition, these earlier programs were not focused on buildings vital for post-earthquake response and recovery. As a result, the State does not have an overall record identifying 1) buildings which have already been mitigated for seismic vulnerabilities, 2) buildings assessed and determined to be acceptable, or 3) buildings in either category which are needed for post-disaster response and recovery operations.

The need for understanding the seismic vulnerability of state-owned buildings was addressed by the Cal VIVA team by proposing the establishment of a state-managed repository for building assessment information, known as the State Reporting Plan. Through the State Reporting Plan, necessary seismic assessment and mitigation actions for state-owned buildings can be identified, implemented, and monitored. The implementation of the State Reporting Plan will be divided into two phases. Phase One: Vital Building will focus on recording and maintaining data for buildings vital for response and recovery. Phase Two: State-owned Buildings will focus on recording and maintaining data on all state-owned buildings.

Phase One: Vital Buildings

The State Reporting Plan will be a repository for information from departments responsible for seismically vulnerable building stock deemed necessary for post-disaster response and recovery operations. As part of Phase One, the State Reporting Plan will be populated with information developed during the Cal VIVA project, which represents a partial itemization focused only on buildings considered vital for response and recovery. Full implementation of Phase One will be complex due to the large number of departments involved in the response and recovery efforts.

Phase One of the State Reporting Plan will implement a framework to track seismic assessments and mitigations at four levels, with each level increasing in detail as follows.

- **Level 1: State Hazard Mitigation Plan Reporting** is an overview of statewide assessment and mitigation work at the department level and will be reported through State Hazard Mitigation Plan updates, which presently occur every three years.
- **Level 2: Statewide Buildings Database** consists of a summary of each individual building assessment as recorded in a state-maintained database.
- **Level 3: Department Seismic Mitigation Plans** are the individual departmental plans that contain that department's approach to a department-wide mitigation effort. Each department will maintain its own plan and forward copies of its Department Seismic Mitigation Plans to Cal OES.
- **Level 4: Individual Building Assessments/Mitigation Reports** are the department's individual detailed building assessment reports. These reports will be housed at each department and updated as needed.

Phase Two: State-owned Buildings

As funding permits, the inventory recorded in the State Reporting Plan will be expanded to include information about all state-owned buildings, such as those buildings assessed as part of Proposition 122, and existing and future work by departments and agencies such as the University of California, the California State University, and the Administrative Office of the Courts. The numbers of these buildings is estimated to be in the hundreds or thousands, and many were likely assessed using methodologies different than those developed by Cal VIVA. Retrieving and normalizing the data may take significant effort. A systematic approach will need to be developed to capture existing and future assessment information.

Implementation of Department Plans and State Reporting Plan

The development of the State Reporting Plan creates a method of consolidating and organizing the department information in a way that is useful for the individual departments and for California Governor's Office of Emergency Services (Cal OES) at a statewide level. The implementation of the plan will require additional ongoing work on the part of the departments and Cal OES. Development of the Cal VIVA department plans and implementation of the State Reporting Plan will require approval and coordination at many levels of the state government. This implementation is essential to assure that the State can respond in an effective and timely manner after an earthquake. Each department that has emergency functions will need to participate in this effort. However, the Cal VIVA requirements are not the primary mission of those departments, and it will be difficult to find the resources to meet this need due to competing priorities.

A strategy for implementation of the State Reporting Plan involving eight key steps is shown below. Steps 1 – 7 are expected to take place over a three- to five-year cycle, whereas Step 8 (Phase 2: State-Owned Buildings) may take substantially longer.

Create the Reporting Framework

1. Cal OES appoints Cal VIVA coordinator to oversee the development of the Department Mitigation Plans, state reporting data, and to review and manage the collection of plans and data from the departments.
2. FEMA's Hazard Mitigation Grant Program guidelines are modified to include funding for Cal VIVA implementation to provide some revenue support for the State Reporting Plan effort and individual department retrofit project funding.
3. Cal OES disseminates request (and/or directive) to prepare department plans on a three- to five-year cycle. Of the several options available for implementing Step 3, the issuance of an Executive Order by the Governor could be a reasonable approach.

Phase One: Vital Buildings

4. Departments conduct Individual Building Assessments/Mitigation Reports of seismically vulnerable buildings under their ownership.
5. Departments prepare and transmit their Department Seismic Mitigation Plans to Cal OES.
6. Individual building data is uploaded to the statewide database.
7. Cal OES reports progress monitoring data in the SHMP.

Phase Two: State-owned Buildings

8. Cal OES initiates Phase Two as time and resources permit.

Conclusions

Cal VIVA I developed and tested a methodology to identify and mitigate individual seismically vulnerable state-owned buildings vital for response and recovery after an earthquake. Cal VIVA II and Cal VIVA III continued this work and developed a Department Seismic Mitigation Plan which incorporates a systematic approach to consolidate a department's vital building stock vulnerability and to prioritize mitigations. The development of these plans requires a significant investment of staff time and department resources. This investment is further strained by the lack of engineering data and site knowledge about individual buildings, increasing the complexity of the building assessments. The following recommendations were developed to address this obstacle.

- Cal VIVA III developed and tested a template to aid a department in the development of its Department Seismic Mitigation Plans. Use of this template will simplify the process and create more uniformity in the plans, as demonstrated throughout testing of the template during Cal VIVA III. However, preparation of the development of the department plans is a complex and time-consuming effort that requires additional resources, such as training workshops and additional aids and, for some departments, external consultants.
- As Cal VIVA moves beyond buildings that are vital to the response and recovery and into the review of the seismic vulnerability of all state-owned buildings, the need for additional staff time will become more acute. This may be partially addressed by the implementation of a rapid-screening system like the system documented in FEMA 154 Rapid Visual Screening of Buildings for Potential Seismic Hazards.

The State Reporting Plan as developed in Cal VIVA III is a viable framework to record and measure the seismic vulnerability of state-owned buildings. Successful implementation of the State Reporting Plan will require a continuing effort to document the constantly changing seismic vulnerability of vital buildings through mitigation projects and department modifications to their Department Seismic Mitigation Plans.

Increasing the resiliency of the State of California must be a goal for all its citizens. In the past, an enormous amount of work has been done to reduce seismic vulnerability and improve the safety for its constituents. That work continues today in State agencies, counties, cities, homes, and businesses across the public and the private sector. Cal VIVA I, Cal VIVA II, and Cal VIVA III developed and tested a unified approach that will, over time, reduce the seismic vulnerability of all state-owned buildings. Implementation of two main areas of Cal VIVA – development of Department Seismic Mitigation Plans and implementation of a State Reporting Plan – will create a framework that will reduce disaster losses, optimize response, and improve the resiliency of the State. Working together, we can increase our knowledge, work to secure funding, and systematically reduce the seismic vulnerability of California.