Detailed Methodology Report

CALIFORNIA SUPERIOR COURT BUILDINGS

SEISMIC RENOVATION
FEASIBILITY STUDIES PROJECT

PREPARED BY ARUP

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JUDICIAL COUNCIL
OF CALIFORNIA

ADMINISTRATIVE DIVISION
FACILITIES SERVICES

Contents

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I. INTRODUCTION

In January 2018, the Judicial Council of California Facilities Services engaged Arup, CO Architects, and MGAC (herein referred to as the consultant team) to perform a seismic renovation feasibility study for 26 court buildings in California. The study involved developing a conceptual seismic retrofit scheme for each building, determining the collateral impacts and associated construction costs of the retrofit schemes, and performing cost-benefit analyses to determine the most appropriate renovation strategy for each building.

This report provides additional detail about the methodology used by the consultant team as part of the seismic renovation feasibility study. Bolded terms throughout this report are explained in more detail in the glossary in Appendix A.

A. Background and Context

The Trial Court Facilities Act of 2002 (Sen. Bill 1732; Stats. 2002, ch. 1082) initiated the transfer of responsibility for funding, operation, and ownership of court buildings from the counties to the Judicial Council and State of California. The act required most existing California court buildings to be seismically evaluated and assigned a risk level, with VII being the worst and I being the best. Facilities evaluated as Risk Level V or worse were ineligible for transfer to the state because they were deemed to have unacceptable seismic safety ratings. In total, 225 court buildings (comprising 300 **building segments**) were evaluated; 72 segments were rated Risk Level IV, while 228 were rated Risk Level V.

In 2015, the Judicial Council engaged Rutherford + Chekene (R+C) to develop a more refined **seismic risk rating** (SRR) for the 139 Risk Level V building segments that remained in the council's portfolio since the initial 2002 study. Using the Federal Emergency Management Agency's (FEMA) Hazus Advanced Engineering Building Module, R+C assigned an SRR to each building segment based on the relative **collapse probability** obtained from the 2003 seismic assessment of the structure (R+C 2017).

Informed by the SRRs, the Judicial Council Trial Court Facility Modification Advisory Committee authorized the California Superior Court Buildings Seismic Renovation Feasibility Studies project on August 28, 2017. The committee directed Facility Services staff to study 27 buildings that meet specific criteria. For a court building to be a candidate for the renovation feasibility study, it needed to meet all the following criteria:

- It has a Very High or High SRR.
- It is not being replaced by an active new courthouse construction project.
- It is not subject to a memorandum of understanding restricting transfer because of historic building designation.
- It is owned by the Judicial Council or has a transfer of title pending, or the court occupies more than 80 percent of a county owned building.

- The investment would extend its useful life for long-term service to the public.

Facilities Services engaged the consultant team in January 2018 to perform the study, which was completed in December 2018. One court building was removed during the study due to a lack of structural and architectural drawings. The 26 court buildings studied have a total area of approximately five million gross square feet and comprise 43 building segments. Figure 1 shows the location and area of each court building included in the study.

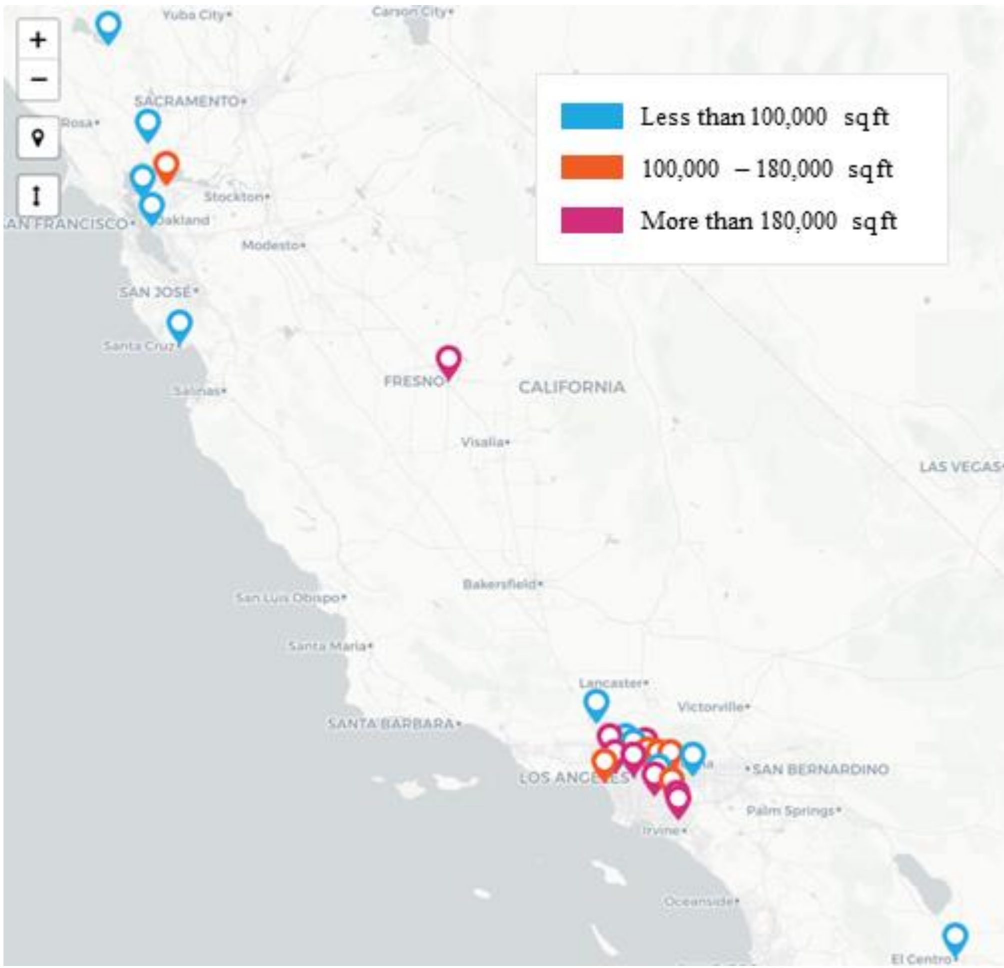

Figure 1. Location and Size of the 26 Court Buildings Assessed in This Study

B. Summary of Project Approach

As part of the seismic renovation feasibility study, the consultant team reviewed structural and architectural drawings and previous seismic assessment reports to understand the critical seismic deficiencies and general layout of each court building. The team then conducted a site inspection and interviewed court staff to verify critical seismic deficiencies and document overall facility conditions before performing a supplemental seismic assessment to confirm previously identified deficiencies and identify new ones.

The consultant team then designed a conceptual retrofit scheme for each court building to address the critical seismic deficiencies identified from the supplemental seismic evaluation. The primary objective of the retrofit scheme is to reduce the seismic risk level of the court building from Risk Level V to IV, typically by strengthening existing **structural components,** adding new ones, or a combination of both.

The team then determined the **collateral impacts** of the retrofit scheme and identified code-required upgrades to accessibility and fire and life safety systems. Collateral impacts refer to repair work to **nonstructural components** (e.g., walls, ceilings, lighting, carpeting) made necessary by the retrofit. This scope of work is referred to as the **baseline retrofit option (Option 1)** because it represents the minimum required effort to achieve Risk Level IV seismic performance.

Because a seismic retrofit can be highly invasive, it provides an opportunity to make additional building repairs and upgrades for relatively little incremental cost. The Judicial Council Facilities Services staff asked the consultant team to include approved, unfunded facility modifications in addition to the minimum scope of work required in the baseline retrofit. Approved, unfunded facility modifications, referred to as **priority upgrades**, include building maintenance and systems upgrades that have been approved by the Judicial Council or Superior Court but do not have specific funding sources identified yet. Consequently, these facility modifications would be attractive candidates for inclusion in a seismic renovation. This option is referred to as the **priority upgrades retrofit option (Option 2)**.

Furthermore, because a seismic retrofit can be extremely costly, the consultant team also included a full renovation option and two replacement options for the purposes of benchmarking. While these three options did not involve any design work, they were included in the study as a reference point to identify situations where it may be more cost effective to either fully renovate or replace a court building. The **full renovation option (Option 3)** involves the same seismic retrofit as the baseline retrofit, plus full demolition and replacement of the building interior down to the structural skeleton and removal and replacement of the exterior wall and roof cladding. The first replacement option, referred to as the **replace to 2016 CBC option (Option 4)**, involves replacing the existing court building with a new facility that satisfies the requirements of the 2016 **California Building Code** (CBC; CBSC 2016a). The second replacement option, referred to as the **replace to beyond code option (Option 5)**, involves replacing the existing court building with a new facility that goes beyond the minimum requirements of the 2016 CBC to achieve more resilient seismic performance (e.g., reduced damage, repair costs, and downtime).

A total of five retrofit and replacement options were considered for each court building. The consultant team developed construction cost estimates and durations for each option and compared these costs to the benefits of retrofitting or replacing the court building. The primary benefit of retrofitting or replacing the court building is reduced seismic risk relative to the existing court building, including reduced collapse probability, fatalities, repair costs, and downtime. Additional benefits stemming from retrofitting or replacing the court building (e.g., improved energy efficiency, accessibility, fire and life safety, security, employee productivity) were not quantified, though the costs of these upgrades were included in the cost-benefit analysis. The design team developed a risk model for each retrofit and replacement option to predict the reduction in seismic risk. Refer to Section IV for additional discussion of the seismic risk assessment methodology.

The consultant team then performed cost-benefit analyses to compare the financial effectiveness of the five retrofit and replacement options for each court building. The benefit-cost ratio measures the benefits of an option relative to its cost and was the primary consideration in the Judicial Council Facilities Services staff's decision of which retrofit or replacement option to select. Refer to Section V for additional discussion of the cost-benefit methodology.

The conceptual retrofit schemes were reviewed by R+C, the structural peer reviewer retained by the Judicial Council for this study, to confirm the validity and appropriateness of the proposed interventions. R+C also reviewed results from the seismic risk assessments and cost-benefit analyses.

C. Report Organization

Section II documents minimum code requirements for seismic retrofits of court buildings in California. Section III describes the approach for evaluating and designing the seismic retrofits in this study. Section IV explains the seismic risk assessment methodology for predicting casualties, repair costs, and downtime for existing court buildings and the retrofit and replacement schemes across a range of earthquake intensities. Section V details the cost-benefit analysis methodology for evaluating the financial effectiveness of retrofitting or replacing each of the 26 court buildings in this study.

Appendix A provides a list of abbreviations and glossary of terminology used throughout this report. Appendix B provides a letter from R+C stating their professional opinion about overall appropriateness or validity of the methodology used for the seismic renovation feasibility study.

II. MINIMUM CODE REQUIREMENTS FOR RETROFITS

This section summarizes the minimum code requirements for seismic retrofits of California court buildings. These requirements form the basis for the scopes of work for the three retrofit options included in the feasibility study: baseline retrofit, priority upgrades retrofit, and full renovation. Per Table 317.5 of the 2016 **California Existing Building Code** (CEBC), all three retrofit options must achieve the following two-tiered seismic performance objective (CBSC 2016c):

1. Level 1: In the 20 percent in 50-year seismic event (i.e., the 225-year earthquake), **life safety performance** for both structural and nonstructural components
2. Level 2: In the 5 percent in 50-year seismic event (i.e., the 975-year earthquake), **collapse prevention performance** for the structure, while the performance of nonstructural components is not considered

As documented in the sections that follow, this two-tiered seismic performance objective is equivalent to (and therefore achieves) Risk Level IV performance, which is the minimum performance level required by the Judicial Council for the seismic retrofit of court buildings. This two-tiered objective is also equivalent to the basic performance objective for existing buildings (BPOE) for Risk Category II structures, as outlined in ASCE 41-13 (2014). While court buildings are classified as Risk Category III structures in the 2016 California Building Code (CBC), which governs how new buildings are designed and constructed, the two-tiered performance objective specified in Table 317.5 of the 2016 CEBC translates to a Risk Category II classification per ASCE 41-13. Note that the risk categories in ASCE 41-13 and the 2016 CBC, which provide the basis for applying earthquake provisions based on a building's use or occupancy, are distinct from Judicial Council risk levels, which measure the damageability of a court building in an earthquake.

Per additional requirements in the 2016 CEBC, the seismic retrofit of a court building will trigger required upgrades to both accessibility and fire and life safety systems (CBSC 2016c).

Section II.A lists the sources of information reviewed to determine minimum retrofit requirements for court buildings. Section II.B discusses the **authorities having jurisdiction** over different aspects of the seismic retrofit process. Section II.C discusses minimum seismic retrofit requirements for Judicial Council court buildings. Section II.D discusses minimum accessibility upgrades triggered by the seismic retrofit, while Section II.E discusses minimum fire and life safety upgrades. Section II.F describes the three retrofit options (and two replacement options) considered as part of this study. Section II.G provides relevant excerpts from the 2016 CEBC that are referenced in the following sections.

A. Sources of Information

To determine the minimum retrofit requirements for court buildings in California, the consultant team reviewed various written documents that serve as the regulatory framework governing the seismic retrofit of court buildings in California. These include the following documents:

- 2016 California Existing Building Code (CBSC 2016a)
- Trial Court Facilities Act of 2002 (Sen. Bill 1732; Stats. 2002, ch. 1082)
- Leasing memos from the Judicial Council (2008) and the California Department of General Services (DGS; 2009)
- American Society of Civil Engineers (ASCE) Standard 41-13, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE 2014)

The consultant team also had numerous conversations with Judicial Council Facilities Services staff and engineers at R+C, the peer reviewer for the feasibility study, to discuss retrofit requirements.

B. Authorities Having Jurisdiction

Section 70391(b) of Trial Court Facilities Act of 2002 gives the Judicial Council "the full range of policymaking authority over trial court facilities, including, but not limited to, planning, construction, acquisition, and operation, to the extent not expressly otherwise limited by law" (Sen. Bill 1732; Stats. 2002, ch. 1082). Based on this language and conversations with the Judicial Council, including the project kick-off meeting on January 26, 2018, Table 1 summarizes the **authorities have jurisdiction** over different aspects of the seismic retrofit of court buildings in California, including structure, accessibility, and fire and life safety.

Table 1. Authorities Having Jurisdiction Over the Seismic Retrofit of Court Buildings

Retrofit Aspect	Authority Having Jurisdiction	Source	Notes
Structure	Judicial Council	Section 1.2.1.2 of the 2016 CEBC	The Judicial Council hires a structural peer reviewer to verify compliance with California Building Standards Code, which includes the 2016 CEBC.
Accessibility	Division of the State Architect	Section 1.9 of the 2016 CEBC	
Fire and life safety	State Fire Marshal	Section 1.11 of the 2016 CEBC	

C. Seismic Retrofit Requirements

Seismic retrofits of court buildings in California are subject to the requirements of both the 2016 CEBC and the Judicial Council. These requirements are reviewed in the following sections, culminating with a determination of the minimum seismic retrofit requirements used in this study. Figure 2 provides a flowchart summarizing the retrofit requirements discussed below.

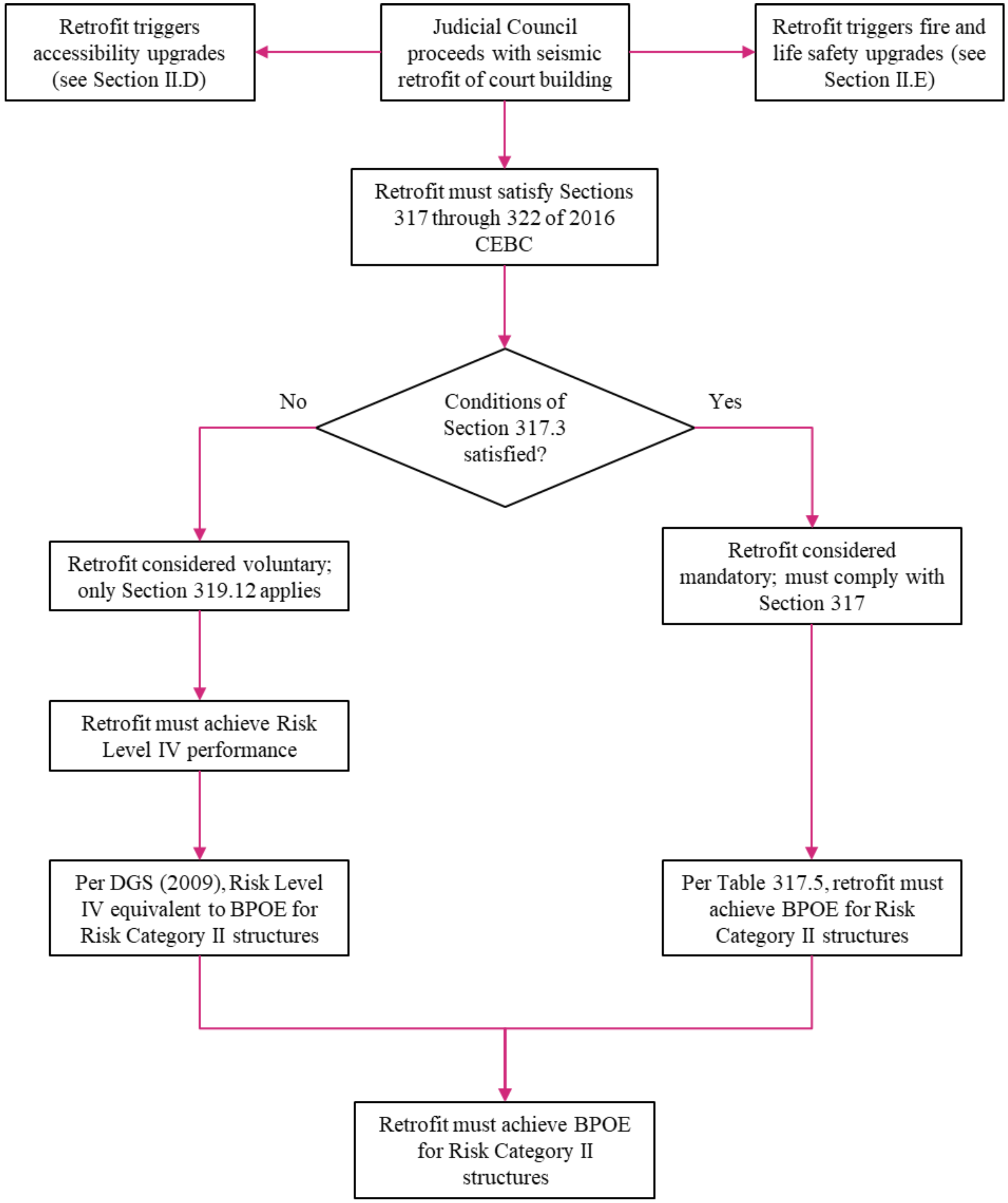

Figure 2. Summary of Retrofit Requirements of Court Buildings in California

1. Minimum Seismic Retrofit Requirements per 2016 CEBC

Sections 317 through 322 of the 2016 CEBC prescribe “minimum standards for earthquake evaluation and design for retrofit of existing state-owned structures, including buildings owned by… the Judicial Council” (CBSC 2016c, Section 301.1). Section 317.3

specifies conditions under which any retrofit, repair, or modification of a building must adhere to the minimum requirements of the 2016 CEBC. Refer to Section II.G.1 for the code language. If none of the conditions of Section 317.3 are satisfied, then the retrofit is considered voluntary and only the provisions of Section 319.12 of the CEBC apply. In overview, these provisions require that a voluntary seismic retrofit not reduce the capacity of or increase the loading on existing structural elements, or create a "dangerous condition." However, Section 319.12 stops short of prescribing minimum performance objectives for voluntary seismic retrofits (CBSC 2016c). Refer to Section II.G.3 for specific code language.

If any of the conditions in Section 317.3 are met, the retrofit must satisfy the provisions of Section 317 of the 2016 CEBC, herein referred to as a mandatory retrofit. Of the several conditions listed, the most likely to be triggered is that of the total construction costs exceeding 25 percent of the cost of replacing the building. Based on previous experience, the consultant team anticipated that a typical seismic retrofit of a court building would exceed this threshold; therefore, the retrofit options considered in this study were required to meet the minimum requirements of the CEBC as specified in Section 317. After designing each retrofit and estimating its cost, the consultant team verified that the 25 percent cost threshold is triggered for all court buildings.

Table 317.5 of the 2016 CEBC prescribes minimum seismic performance objectives for a retrofit that meets any of the conditions of Section 317.3. Refer to Section II.G.2 for specific code language for Table 317.5. For the seismic retrofit of a Judicial Council court building, the first row of Table 317.5 governs, and the retrofit must achieve the following two-tiered performance objective:

1. Level 1: In the 20 percent in 50-year seismic event (i.e., the 225-year earthquake), life safety performance for both the structure and nonstructural components.
2. Level 2: In the 5 percent in 50-year seismic event (i.e., the 975-year earthquake), collapse prevention performance for the structure, while the performance of nonstructural components is not considered.

This performance objective is equivalent to the BPOE for Risk Category II structures specified in ASCE 41-13. While court buildings are classified as Risk Category III structures in the 2016 CBC, which governs how new buildings are designed and constructed, the two-tiered performance objective specified in Table 317.5 of the 2016 CEBC translates to a Risk Category II classification per ASCE 41-13.

2. Minimum Seismic Retrofit Requirements per the Judicial Council

Regardless of whether the seismic retrofit is deemed voluntary or mandatory per the 2016 CEBC, the minimum performance requirements specified by the Judicial Council will govern the retrofit. Per previous conversations with the Judicial Council Facilities Services staff, the seismic retrofit of court buildings must, at a minimum, achieve Risk

Level IV performance. Language in Trial Court Facilities Act of 2002 reinforces this understanding, as a building evaluated as Risk Level V or worse is classified as having an “unacceptable seismic safety rating.”

Consequently, the following two situations are possible:

1. If the retrofit is deemed voluntary per the 2016 CEBC, achieving Risk Level IV performance is the sole requirement.
2. If the retrofit is deemed mandatory per the 2016 CEBC, the retrofit is required to achieve the more stringent of Risk Level IV performance or the two-tiered performance objective in Table 317.5 of the 2016 CEBC, though, as will be demonstrated in the following paragraphs, these two performance requirements are equivalent.

Since the designation of the risk levels used by the Judicial Council is not recognized in any of the governing building code standards (including the CEBC, which references ASCE 41), it is essential to establish the definition for Risk Level IV so it can be related to the regulatory requirements of current code (see Section II.C.1).

Towards this end, the consultant team reviewed two documents that explicitly define Risk Level IV performance: one written by the California Department of General Services (DGS; 2009) and one written by the Judicial Council (2008). DGS (2009) outlines requirements for conducting independent seismic reviews of buildings the DGS might lease. It states that the DGS will not approve for occupancy a newly leased building if it is evaluated as Risk Level V or higher. The document contains a table that defines “Earthquake Damageability Levels for Existing Buildings,” which the consultant team interpreted as being equivalent to the risk levels used by the Judicial Council. Table 2 reproduces the original table from DGS (2009). The table defines Damageability Level IV, which is equivalent to Risk Level IV, as “a building evaluated as meeting or exceeding the requirements of Chapter 34 of CBC [now the CEBC] for Occupancy Category I-III performance criteria [now referred to as Risk Categories].”

As described in preceding sections, the minimum code requirements for a seismic retrofit of a court building depend on whether it is considered voluntary or mandatory. However, using the definition provided for Risk Level III in Table 2 and previous versions of the CBC, it is possible to back-calculate that Risk Level IV performance is equivalent to the two-tiered seismic performance objective in Table 317.5 of the 2016 CEBC. More specifically, from Table 2, Risk Level III involves replacing the BSE-R (i.e., the 225-year earthquake, which in ASCE 41-13 is the **BSE-1E**) with the BSE-1 (475-year earthquake, which in ASCE 41-13 is the **BSE-1N**), and the BSE-C (975-year earthquake, which in ASCE 41-13 is the **BSE-2E**) with the BSE-2 (2,475-year earthquake, which in ASCE 41-13 is the **BSE-2N**), implying that Risk Level IV performance involves using the same seismic hazard levels as specified in Table 317.5 of the 2016 CEBC (i.e., BSE-R and BSE-C).

Table 2. Earthquake Damageability Levels (Risk Levels) for Existing Buildings (DGS 2009)

Rating Level [1,5]	Definitions based upon California Building Code (CBC) requirements for existing buildings [2]	Implied Risk to Life [3]	Implied Seismic Damageability [4]
I	A building evaluated as meeting or exceeding the requirements of CBC Chapter 34 for Occupancy Category IV performance criteria for a new building.	Negligible	0% to 10%
II	A building evaluated as meeting or exceeding the requirements of CBC Chapter 34 for Occupancy Category IV performance criteria with BSE-R and BSE-C categories replacing those given in Chapter 34.	Insignificant	0% to 10%
III	A building evaluated as meeting or exceeding the requirements of CBC Chapter 34 for Occupancy Category I-III performance criteria with BSE-1 and BSE-2 categories replacing BSE-R and BSE-C as given in Chapter 34 ; alternatively a building meeting CBC requirements for a new building.	Slight	5% to 20%
IV	A building evaluated as meeting or exceeding the requirements of CBC Chapter 34 for Occupancy Category I-III performance criteria.	Small	10% to 30%
V	A building evaluated as meeting or exceeding the requirements of CBC Chapter 34 for Occupancy Category I-III performance criteria only if the BSE-R and BSE-C values are reduced to 2/3 of those specified for the site.	Serious	20% to 50%
VI	A building evaluated as not meeting the minimum requirements for Level V designation and not requiring a Level VII designation.	Severe	40% to 100%
VII	A building evaluated as posing an immediate life-safety hazard to its occupants under gravity loads. The building should be evacuated and posted as dangerous until remedial actions are taken to assure the building can support CBC prescribed dead and live loads.	Dangerous	100%

Notes:
1. Earthquake damageability levels are indicated by Roman numerals I through VII. Assignments are to be made following a professional assessment of the building's expected seismic performance as measured by the referenced technical standard and earthquake ground motions. Equivalent Arabic numerals, fractional values, or plus or minus values are not to be used and are undefined. These assignments were prepared by a task force of state agency technical personnel, including CSU, UC, DGS, DSA, and AOC. The ratings apply to structural and non-structural elements of the building as contained in Chapter 34 , CBC requirements.
2. Chapter 34 of the California Building Code, current edition, regulates existing buildings. It uses and references the American Society of Civil Engineers Standard *Seismic Rehabilitation of Existing Buildings, ASCE-41*. All earthquake ground motion criteria are specific to the site of the evaluated building. The CBC definitions for earthquake ground motions to be assessed are paraphrased below:
   - BSE-2, the 2,475-year return period earthquake ground motion, or the lesser of the Maximum Capable Earthquake for the site under certain limiting conditions.
   - BSE-C the 1,000-year return period earthquake ground motion.
   - BSE-1, two-thirds of BSE-2 value, nominally, the 475-year return period earthquake ground motion.
   - BSE-R the 225-year return period earthquake ground motion.
3. *Implied Risk To Life* is a subjective measure of the threat of a life threatening injury or death that is expected for an average building in compliance with the indicated technical requirements. The terms *negligible* through *dangerous* are not specifically defined, but are linguistic indications of the relative degree of hazard posed to an individual occupant.
4. *Implied Damageability* is the level of damage expected to the average building in compliance with the indicated technical requirements when a BSE-2 level earthquake occurs. Damage is measured as the ratio of the cost to repai the structure divided by the current cost to reconstruct the structure from scratch. Such assessments are to be completed to the requirements of ASTM E-2026, where the damage ratio is the SEL evaluated at Level 1 or higher ir order to be considered appropriate.
5. In those cases where the engineer making the assessment using the requirements for a given rating level concludes that the expected seismic performance is consistent with a one-level higher or lower level rating, this alternative rating level may be assigned if and only if an independent technical peer reviewer concurs in the evaluation. The peer review must be completed consistent with the requirements of Section 3420, 2007 CBC.

Risk Level III is also described as meeting the CBC requirements for new buildings. This is generally understood to mean life safety performance in the BSE-1 and collapse prevention performance in the BSE-2. Consequently, Risk Level IV is equivalent to the two-tiered seismic performance objective in Table 317.5 of the 2016 CEBC.

The Judicial Council's (2008) *Court Facilities Planning: Seismic Safety Policy for Leased Buildings* report specifies that the Judicial Council will not approve leasing or renewal of a lease in a building if it is evaluated as Risk Level V or higher. The document defines Risk Level IV in a similar fashion as DGS (2009).

Based on DGS (2009) and the Judicial Council (2008), the consultant team determined that for a retrofit to achieve Risk Level IV performance, it must satisfy the requirements for mandatory seismic retrofits in the 2016 CEBC. Consequently, use of Section 319.12 is prohibited in a retrofit of a court building because its provisions do not ensure that the two-tiered performance objective in Table 317.5 of the 2016 CEBC is achieved.

D. Triggered Upgrades to Accessibility

Chapter 11B of the 2016 CBC specifies minimum accessibility requirements for public buildings. In accordance with the Division of the State Architect's 2016 California Access Compliance Advisory Reference Manual commentary on Section 202.3 of Chapter 11B of the 2016 CBC, an accessible primary entrance, toilet and bathing facilities, drinking fountains, signs, public telephones, and path of travel connecting these elements shall be provided in existing buildings. If these items are not already in compliance, a seismic retrofit would trigger accessibility upgrades to the primary entrance, the facilities that serve it (e.g., toilets, drinking fountains, signs, public telephones), and the path of travel between them.

In addition, when alterations or additions are made to existing buildings, an accessible path of travel to the specific area (or areas) of alteration or addition shall be provided. The accessible path of travel shall include:

- Toilet and bathing facilities serving the area
- Drinking fountains serving the area
- Public telephones serving the area
- Signs

Consequently, any area impacted by the conceptual retrofit scheme (e.g., strengthening of a concrete wall in an administrative space) would require accessibility upgrades to the facilities serving the impacted area (e.g., toilets, drinking fountains, signs, public telephones) and the path of travel from the primary entrance.

The 2016 CBC also requires accessibility upgrades whenever the primary use or function of a building is altered; however, such changes in use or function are not anticipated.

The extent of compliance with these accessibility requirements shall be provided by equivalent facilitation or to the greatest extent possible without creating an unreasonable hardship. Should the enforcing agency, the Division of the State Architect, determine the cost of full applicable compliance is an unreasonable hardship, then the cost compliance shall be limited to 20 percent of the adjusted construction cost of alterations, structural repairs, or additions (CBC Section 202.4, Exception 8; CBSC 2016a). The consultant team anticipates the Judicial Council would be unable to obtain a hardship exemption.

E. Triggered Upgrades to Fire and Life Safety

The 2016 California Fire Code (CFC) specifies "minimum requirements… to safeguard the public health, safety and general welfare from the hazards of fire, explosion or dangerous conditions in new and existing buildings" (CFC Section 1.1.2; CBSC 2016b). In accordance with 2016 CFC, minimum means of egress in compliance with requirements of the building code at the time of construction and provisions as detailed in 2016 CFC 1104.1 shall be provided.

Based on observations of the existing court buildings, the following recommendations are necessary to bring existing conditions into compliance:

- Provide emergency responder radio coverage (subject to determination by fire code official)
- Provide standpipes in buildings with occupied floors located more than 50 feet above the lowest level of fire department access or more than 50 feet below the highest level of fire department access (CFC Section 1103.6)
- Provide fire alarm system (CFC Section 1103.7), with both automatic and manual fire alarm systems in Group I-3 occupancy (CFC Section 1103.7.4)

Ultimately, fire and life safety upgrades are at the discretion of the State Fire Marshal. For the purposes of this study, the consultant team assumed that all required upgrades specified in the 2016 CFC would be triggered by a seismic retrofit. However, if the existing court building does not currently have a fire sprinkler system, the seismic retrofit design does not include installing one, though the State Fire Marshal may require it. In aggregate, these assumptions are reasonably conservative and would likely result in upper-bound estimates of fire and life safety construction costs.

F. Retrofit and Replacement Options to Evaluate

Based on the minimum retrofit requirements summarized in previous sections, the consultant team, with input from Facilities Services, established several retrofit and replacement options to be considered for each court building. The five options — three retrofit options and two replacement options — are summarized in the text below and in Table 3.

For court buildings with multiple segments, a conceptual retrofit scheme was developed for each building segment. For a small number of court buildings, not all segments are rated Risk Level V, meaning they are not required to be retrofitted to achieve a level of seismic performance consistent with the Trial Court Facilities Act of 2002. However, because the building segments typically function together as a single facility (which often has only one public entrance), the decision was made to develop retrofit schemes, collateral impacts, and construction costs for all building segments.

1. **Baseline retrofit**: includes seismic upgrades to structural and nonstructural components (e.g., stairs, elevators, ceilings, lights, partitions) to achieve Risk Level

IV performance (i.e., ASCE 41-13 BPOE for Risk Category II structures), nonstructural repairs made necessary by the retrofit, and triggered upgrades to accessibility and fire and life safety systems. This option represents the minimum level of effort and expenditure to mitigate the seismic risk at each court building.

2. **Priority upgrades retrofit**: includes the same upgrades as Option 1, plus any priority upgrades, which refer to approved but unfunded facility modifications. This option was included in the study because seismic retrofits often provide an opportunity to upgrade outdated or deficient building systems (which would be highly disruptive) at relatively little additional cost.

3. **Full renovation**: includes the same seismic upgrades to structural components as Option 1, plus full demolition and replacement of the building interior down to the structural skeleton, including removal of the exterior wall and roof cladding. Consequently, the necessary nonstructural seismic upgrades, nonstructural repairs, triggered upgrades to accessibility and fire and life safety systems, and priority upgrades are not specifically considered in this option, since a new building interior will incorporate these features. This option was included because some retrofits are highly invasive, so that a complete interior and exterior renovation would provide direct access for improvement of structural frame connections, and hence might not entail much additional cost compared to retrofit Option 1 or 2. Design of the fully renovated interior and exterior is beyond the scope of this study.

4. **Replace to 2016 CBC**: involves replacing the existing court building with a new facility that satisfies the requirements of the 2016 CBC, sized in accordance with the Judicial Council California Trial Court Facilities Standards (2011). The size of a replacement building was determined by using the number of court departments at the existing court building and the median gross area per court department for California Superior Court buildings of similar scope constructed in the recent decade. In addition, a replacement court building would contain only Superior Court functions, resulting in a replacement building size that is in general alignment with the Judicial Council Standards for new court buildings, but may be substantially smaller or larger than the existing building. This replacement option was included for the purposes of benchmarking because some retrofit schemes are so disruptive and costly that it might be more cost effective to replace the court building with a new facility. The construction costs for replacement buildings are derived from the Judicial Council cost-model database of construction costs for California Superior Court buildings of similar scope and location constructed in the recent decade. Design of the new court facility is beyond the scope of this study.

5. **Replace to beyond code**: involves replacing the existing court building with a new facility that achieves a seismic performance level exceeding the minimum requirements of the 2016 CBC, sized in accordance with the Judicial Council California Trial Court Facilities Standards (2011). This facility is expected to be more

resilient — experience less damage and downtime in future earthquakes — than a code-compliant building. The Resilience-based Earthquake Design Initiative (REDi) framework outlines criteria for resuming building operations quickly after an earthquake (Arup 2013). While a building designed in accordance with REDi criteria has a similar level of seismic safety (i.e., collapse probability) as one designed to the 2016 CBC, a REDi building is explicitly designed to recover functionality within a specified timeframe after a large earthquake (e.g., 30 days for REDi Gold performance). For example, REDi requires equipment anchorage to remain essentially elastic and drift-sensitive components like partitions to accommodate relative displacements with aesthetic damage in the **design basis earthquake**. Code-compliant buildings, on the other hand, are not designed to minimize the type of earthquake-induced damage that can result in significant repair costs and downtime. This option was included because it is often only marginally more expensive (less than 5 percent premium) to construct a more resilient building. The cost premium for this option was assumed to be 5 percent of the cost of Option 4.

Table 3. Retrofit and Replacement Options

Option	Upgrade Options			
	Seismic	Accessibility	Fire and Life Safety	Building Systems
Baseline Retrofit (Option 1)	Minimum*	Primary†	Minimum**	Not considered (unless impacted by retrofit work)
Priority Upgrades Retrofit (Option 2)	Minimum*	Primary†	Minimum**	Priority only††
Full Renovation (Option 3)	Minimum*	Full‡	Full‡	Full‡
Replace to 2016 CBC (Option 4)	New facility			
Replace to Beyond Code (Option 5)	New facility			

* Retrofit achieves Risk Level IV performance, which is equivalent to BPOE for Risk Category II structures as defined in ASCE 41-13. Minimum seismic upgrades apply to all segments of the court building.

† Primary accessibility upgrades address path-of-travel upgrades from the primary entrance to areas impacted by the seismic retrofit, including upgrades to the facilities servicing the impacted areas (e.g., toilets, signage).

‡ Assumes complete building renovation (i.e., full accessibility, fire and life safety, and building systems upgrades). Design of such upgrades is beyond the scope of this study; however, costs are estimated for inclusion in cost-benefit analysis.

** Minimum fire and life safety upgrades include those detailed in Section II.E.

†† Priority building system upgrades (if any) are identified from a list of approved but unfunded facility modification projects submitted to the consultant team by the individual courts. A full facility condition assessment is beyond the scope of this study.

G. Referenced Code Language and Tables

1. CEBC Section 317.3

317.3 Applicability.

317.3.1 Existing state-owned buildings. [BSC] *For existing state-owned structures including all buildings owned by the University of California and the California State University, the requirements of Section 317 apply whenever the structure is to be retrofitted, repaired or modified and any of the following apply:*

1. *Total construction cost, not including cost of furnishings, fixtures and equipment, or normal maintenance, for the building exceeds 25 percent of the construction cost for the replacement of the existing building. The changes are cumulative for past modifications to the building that occurred after adoption of the 1995 California Building Code and did not require seismic retrofit.*
2. *There are changes in risk category.*
3. *The modification to the structural components increases the seismic forces in or strength requirements of any structural component of the existing structure by more than 10 percent cumulative since the original construction, unless the component has the capacity to resist the increased forces determined in accordance with Section 319. If the building's seismic base shear capacity has been increased since the original construction, the percent change in base shear may be calculated relative to the increased value.*
4. *Structural elements need repair where the damage has reduced the lateral-load-resisting capacity of the structural system by more than 10 percent.*
5. *Changes in live or dead load increase story shear by more than 10 percent.*

2. CEBC Table 317.5

TABLE 317.5
SEISMIC PERFORMANCE REQUIREMENTS BY BUILDING REGULATORY AUTHORITY AND RISK CATEGORY.

		PERFORMANCE CRITERIA	
Building Regulatory Authority	Risk Category	Level 1	Level 2
State-Owned [BSC]	I, II, III	BSE-R, S-3, N-C	BSE-C, S-5, N-D
State-Owned [BSC]	IV	BSE-R, S-2, N-B	BSE-C, S-4, N-D
Division of the State Architect - [DSA-SS]	I	BSE-1N, S-3, N-B	BSE-2N, S-5, N-D
Division of the State Architect - [DSA-SS]	II, III	BSE-1N, S-2, N-B	BSE-2N, S-4, N-D
Division of the State Architect - [DSA-SS]	IV	BSE-1N, S-2, N-A	BSE-2N, S-4, N-D
Division of the State Architect - [DSA-SS/CC]	I, II	BSE-1E, S-3, N-C	BSE-2N, S-5, N-D
Division of the State Architect - [DSA-SS/CC]	III	BSE-1E, S-3, N-B	BSE-2N, S-5, N-D
Division of the State Architect - [DSA-SS/CC]	IV	BSE-1E, S-2, N-B	BSE-2N, S-4, N-D

1. *ASCE 41 provides acceptance criteria (e.g. m, rotation) for Immediate Occupancy (S1), Life Safety (S3), and Collapse Prevention (S5), and specifies in Section 2.3.1.2.1 and 2.3.1.4.1 the method to interpolate values for S-2 and S-4, respectively.*
   For nonstructural components, N-A corresponds to the Operational level, N-B to the Position Retention, and N-C to the Life Safety level, and N-D to the Not Considered.
2. *Buildings evaluated and retrofitted to meet the requirements for a new building, Chapter 16 of the California Building Code, in accordance with the exception in Section 319.1, are deemed to meet the seismic performance requirements of this section.*

3. CEBC Section 319.12

319.12 Voluntary modifications to the lateral-force resisting system. *Where modifications of existing structural components and additions of new structural components are initiated for the purpose of improving the lateral-force resisting strength or stiffness of an existing structure and they are not required by other sections of this code, then they are permitted to be designed to meet an approved seismic performance criteria provided that an engineering analysis is submitted that follows:*

1. *The capacity of existing structural components required to resist forces is not reduced, unless it can be demonstrated that reduced capacity meets the requirements of Section 319.8.*
2. *The lateral loading to or strength requirement of existing structural components is not increased beyond their capacity.*
3. *New structural components are detailed and connected to the existing structural components as required by the California Building Code.*
4. *New or relocated nonstructural components are detailed and connected to existing or new structural components as required by the California Building Code.*
5. *A dangerous condition is not created.*

Use of ASCE 41 Tier 1 and Tier 2 deficiency only retrofit procedures are pre-approved for use where Section 317.3 does not require an assessment.

319.12.1 State-owned buildings. [BSC] *Voluntary modifications to lateral force-resisting systems conducted in accordance with Appendix A of this code and the referenced standards of the California Building Code shall be permitted.*

319.12.1.1 Design documents. [BSC] *When Section 319.12 is the basis for structural modifications, the approved design documents must clearly state the scope of the seismic modifications and the accepted criteria for the design. The approved design documents must clearly have the phrase "The seismic requirements of the California Existing Building Code have not been checked to determine if these structural modifications meet the full seismic evaluation and strengthening requirements of Sections 317-322: the modifications proposed are to a different seismic performance standard than would be required in Section 319 if they were not voluntary as allowed in Section 319.12."*

319.12.2 Public schools and community colleges. [DSA-SS, DSA-SS/CC] *When Section 319.12 is the basis for structural modifications, the approved design documents must clearly indicate the scope of modifications and the acceptance criteria for the design.*

III. BASIS OF SEISMIC RETROFIT DESIGN

This section describes the basis of design for the conceptual seismic retrofit schemes developed by the consultant team for the 26 court buildings in this study. The primary intent of the retrofit schemes is to reduce the seismic risk level of the building from Risk Level V to IV. The retrofit schemes are intended for feasibility evaluation and preliminary cost-estimation purposes only.

Section III.A describes the information used to seismically evaluate the existing court buildings and design retrofit schemes. Section III.B summarizes the seismic evaluation methodology, which follows the ASCE 41-13 Tier 1 evaluation procedures with some additional load path calculations. Section III.C describes the methodology for designing the seismic retrofits, which follows Section 1.5 of ASCE 41-13. Section III.D discusses the limitations of the seismic evaluations and retrofit schemes.

A. Available Existing Information

The consultant team considered many sources of information in evaluating the existing court buildings and designing conceptual retrofit schemes. The Judicial Council provided the following documents to the consultant team:

- Original architectural, structural, or as-built drawings for each court building
- Drawings of previous modifications, alterations, or retrofits for each court building
- Seismic assessment reports from 2003 for each court building (based on ASCE 31-03 Tier 1 or 2 procedures)
- Facility conditions report for each court building
- A database containing information about the portfolio of court buildings, including ownership, gross area, area occupied by courts, number of floors, age, **building type**, seismic risk rating (SRR), number of courtrooms, and presence of asbestos

The quality and availability of information available varies from one court building to the next. For locations with missing or illegible drawings, or incomplete seismic assessment reports, the consultant team made appropriate assumptions about structural details, material strengths, location of structural components, and other missing information. In addition to the documents listed above, the consultant team also compiled a large amount of information from additional sources, including notes from interviews with court staff, photos from site inspections, and responses to online questionnaires sent to court staff.

B. Seismic Evaluation Methodology

Following the Trial Court Facilities Act of 2002, most of the 26 court buildings included in this study were evaluated per ASCE 31-03 (a predecessor to ASCE 41-13) and assigned a risk level. The reports from these seismic evaluations (executed c. 2003) were made available to the consultant team. While the reports catalog specific seismic deficiencies for each court building, changes have been made to both the evaluation procedures in ASCE 41-13 and the seismic hazard in California. Considering these changes, the consultant team, in discussion with Judicial Council Facilities Services staff, decided to conduct a **supplemental ASCE 41-13 Tier 1 seismic assessment** of each court building using the most recent seismic hazard information for California, published in 2014 by USGS (Petersen et al. 2014).

The standard ASCE 41-13 Tier 1 Screening Procedure "consists of several sets of checklists that allow a rapid evaluation of the structural, nonstructural, and foundation and geologic hazard elements of the building and site conditions" (Section C3.3.2; ASCE 2014). For the purposes of this study, the consultant team replicated the full ASCE 41-13 Tier 1 checklist and performed relevant calculations pertinent to the changes in the evaluation code (ASCE 41-13 versus ASCE 31-03 [2003]). This included the evaluation of the adequacy of the load path of the entire seismic-force-resisting system through simplified demand-capacity calculations. The load path includes all the horizontal and vertical components participating in the structural response of the building (e.g., floor diaphragms, foundations, vertical components such as walls, frames, and braces) and the connections between each element. These calculations are required to size primary structural components within the retrofit scheme and verify overall feasibility.

A standard ASCE 41-13 Tier 1 seismic evaluation only requires identifying deficient components from standard checklists. It does not require checking the adequacy of supporting elements in the load path once the deficient components have been retrofitted, or checking the performance of the entire seismic-force-resisting system. Both checks were included in the supplemental seismic evaluations performed by the consultant team.

To inform these supplemental evaluations, the consultant team reviewed existing structural drawings and previous ASCE 31-03 Tier 1 and Tier 2 seismic assessments, and conducted site inspections to verify general conformance of existing conditions relative to the provided documents. Site inspections did not include any destructive testing to verify material properties or involve removing finishes or precast exterior cladding to confirm structural properties or specific deficiencies. In addition, no geotechnical investigations were performed to verify soil properties or liquefaction risk. Nor were any system-level analytical models of the structure developed as part of the seismic evaluation process.

C. Conceptual Retrofit Design Methodology

Based on the deficiencies identified by the supplemental seismic evaluation, the consultant team developed a conceptual retrofit scheme for each court building using a simplified version of the process outlined in Section 1.5 of ASCE 41-13. This methodology consists of the following steps:

1. Select a seismic performance objective for the retrofit. For court buildings in California, the seismic retrofit is required to achieve ASCE 41-13 BPOE for Risk Category II buildings. Refer to Section II for additional discussion.

2. Quantify the level of seismicity. Refer to Table 4 for additional information.
3. Obtain as-built information and conduct a site visit using the data collection requirements of ASCE 41-13 Section 6.2 (via Section 319.2 of the 2016 CEBC) as a guide.
4. Evaluate the adequacy of the load path of the existing seismic force-resisting system through simplified demand-capacity calculations. Seismic demands and components capacities are quantified based on ASCE 41-13. Refer to Section III.B and Table 4 for additional information.
5. Conceive retrofit measures to address the deficiencies identified in the ASCE 31-03 seismic evaluation reports from 2003 and the demand-capacity calculations in Step 4 above. Retrofit measures may involve one or more of the following strategies as permitted by ASCE 41-13:
    a. Local modification of structural components, including:
        i. Local strengthening of individual components (e.g., cover plating steel beams or columns, adding wood structural panel sheathing to an existing timber diaphragm)
        ii. Local improvement of the deformation capacity or ductility of individual components (e.g., adding a confinement steel jacket or fiber reinforced polymer wrap around a reinforced concrete column to improve its ability to deform without spalling or degrading reinforcement splices, reducing the cross-section of selected structural components to increase their flexibility and response displacement capacity)
    b. Removal or reduction of existing irregularities, including:
        i. Removal of soft or weak stories by adding braced frames or shear walls within the story
        ii. Removal of torsional irregularities by adding moment frames, braced frames, or shear walls or by partially demolishing structural elements, removing setback towers or side wings, or adding a seismic joint to balance the distribution of mass and stiffness within a story
    c. Global structural stiffening, including the addition of new braced frames or shear walls, or shotcreting over existing concrete walls
    d. Global structural strengthening, including the addition of moment frames, braced frames, or shear walls, though the last two measures may increase the demands due to increased stiffness

e. Mass reduction, including the demolition of upper stories (e.g., penthouses), replacement of heavy cladding or interior partitions, or removal of heavy storage or equipment loads

f. Seismic isolation, including the addition of elastomeric bearings or friction pendulum isolators; retrofits that involve seismic isolation must include a peer review per Section 317.8 of the 2016 CEBC

g. Supplemental energy dissipation, including the addition of fluid viscous dampers or friction-based hysteretic devices; retrofits the involve supplemental energy dissipation must include peer review per Section 317.8 of the 2016 CEBC

While some of the strategies listed above may not be feasible or appropriate for historic structures, none of the 26 court buildings in this study are listed on the state or federal historic registers. Some, however, are classified as local points of historic interest, which may limit the retrofit interventions possible. In these instances, provisions were made to preserve historic elements in place

Table 4. Additional Information About the Seismic Retrofit Design Methodology

Item	Description
Seismic performance objective for retrofits	Retrofits of court buildings in California are required to achieve ASCE 41-13 BPOE for Risk Category II structures. This performance objective comprises two tiers: 1. Level 1: In the 20 percent in 50-year seismic event (i.e., the 225-year earthquake), life safety performance for both the structure and nonstructural components. 2. Level 2: In the 5 percent in 50-year seismic event (i.e., the 975-year earthquake), collapse prevention performance for the structure, while the performance of nonstructural components is not considered. Refer to Section II for additional discussion.
Basis of seismic hazard	While ASCE 41-13 requires the use of seismic design maps developed by USGS in 2008, updated design maps developed by USGS in 2014 (Petersen et al. 2014) provided the basis of seismic hazard for this study.
Soil type	The soil type at each site was classified using Table 20.3-1 of ASCE 7-10, with values of the time-averaged shear-wave velocity in the upper 30 meters (V_{S30}) obtained from USGS (Yong et al. 2016).
Material strength	Nominal values for material strength were taken from existing structural drawings or ASCE 41-13, unless better information was available.
Knowledge factor (κ)	The level of knowledge is classified as “Usual” per Table 6-1 of ASCE 41-13 and the knowledge factor (κ) is set to 1.0. This assumes that “Usual testing” per ASCE 41-13 will be undertaken in the future as part of a more detailed structural evaluation if the court building is retrofitted.

Item	Description
Scope of seismic evaluation	The consultant team performed an enhanced Tier 1 seismic evaluation of the court building. The standard Tier 1 Screening Procedure "consists of several sets of checklists that allow a rapid evaluation of the structural, nonstructural, and foundation and geologic hazard elements of the building and site conditions" (ASCE 2014, Section C3.3.2). For the purposes of this study, the consultant team replicated the full checklist and performed relevant calculations pertinent to the changes in the evaluation code (ASCE 41-13 versus ASCE 31-03 [2003]). This included the evaluation of the adequacy of the load path of the entire seismic force-resisting system through simplified demand-capacity calculations. Refer to Section III.B for additional discussion.
Nonstructural items	Using Table 13-1 of ASCE 41-13 as a guide, nonstructural items that pose a life safety hazard (e.g., heavy items that are not braced, precast hanging elements not adequately anchored) were identified and retrofit measures recommended in accordance with FEMA E-74 (2012a). Where not feasible (e.g., historic facades), alternative mitigation strategies were developed.

D. Limitations

The retrofit schemes developed for this study are intended for feasibility evaluation and preliminary cost-estimation purposes only — the schemes are not detailed retrofit designs and should not serve as construction documents. An architect and Structural Engineer of Record must be engaged by the Judicial Council in the future for design development of constructible retrofit solutions. In addition to the deficiencies identified in the ASCE 31-03 seismic evaluation reports from 2003 and the supplemental seismic evaluations performed as part of this study, the Structural Engineer of Record will need to consider any additional deficiencies that may be identified when the structures are assessed per ASCE 41-13 (or the enforceable standard at that time).

As discussed previously, the retrofit scheme is based on limited information and seismic analysis and, therefore, is subject to the following limitations:

- No materials testing, geotechnical studies, or intrusive testing were performed.
- An analytical model of the building was not developed.
- Design optimization was not carried out (i.e., minimizing collateral impacts and construction costs).

To address these limitations, the consultant team made conservative assumptions about the overall condition of the facility (e.g., material strengths, connection details) to understand and test the feasibility of retrofitting the court building. This likely results in a conservative retrofit scheme and an upper bound on collateral impacts and construction costs (i.e., some retrofit measures may not be required or can be scaled back after further investigation, or alternative retrofit schemes might be possible). While this is appropriate for feasibility studies and budgetary checking, a more thorough engineering study would need to be performed prior to construction.

While the need to strengthen existing foundations or add new ones for new structural elements such as shear walls and braced frames is relatively common in seismic retrofits, rehabilitation of deficiencies in the existing foundation is less common. There are two basic reasons for this:

- Foundation work in existing buildings is expensive.
- There has been relatively little loss of life and property damage resulting from foundation failure in buildings in previous earthquakes (FEMA 2006).

That said, it is important to perform a careful foundation analysis, especially to estimate the extent of soil movement and study the demands that this movement would impose on the superstructure. Large soil movements from rigid body rotation of a shear wall, for example, may have minimal consequences if the entire structure rotates, but may have significant consequences to attached adjacent elements that are not rotating in phase or at all. Estimating soil movements requires a careful geotechnical investigation, which may involve collection and testing of soil samples. Such geotechnical investigations were not performed in this study. In the absence of such investigations, the consultant team used the bearing capacity of soils listed in the original drawings and compared them against the demand imposed by the foundations in the design earthquake. Where the bearing capacity is exceeded, the consultant team suggested a strategy for and extent of foundation retrofit to obtain a cost estimate for the work. When the actual retrofit design is developed in the future, a geotechnical investigation should be performed to assess the need for and extent of foundation retrofit based on soil deformations rather than soil strength.

IV. PROBABILISTIC SEISMIC RISK ASSESSMENT

This section describes the seismic risk assessment performed by the consultant team to predict the seismic performance of each court building across a range of earthquake intensities. Probabilistic seismic risk models were developed for each court building and its five retrofit and replacement options (refer to Section II.F for more information). The risk models predict damage and related consequences (e.g., collapse probability, casualties, repair costs, downtime) for each court building and retrofit/replacement option under various earthquake intensity levels. The seismic risk assessment relies on thousands of computer simulations (Monte Carlo analysis) and various earthquake intensities to predict seismic performance. This is known as a fully probabilistic seismic risk assessment (PSRA).

The PSRA integrates the following information to predict casualties, repair costs, and downtime:

- Quantification of the seismic hazard at six intensities, ranging from frequent to very rare: 45-, 100-, 225-, 475-, 975-, 2,475-year return periods (Section IV.B)
- Anticipated building movements (i.e., engineering demand parameters) from simplified structural analysis at each seismic intensity (Section IV.C)
- Collapse fragilities derived from previous seismic analyses by R+C (Section IV.D)
- Exposure data, including number of people within the building, quantity and type of building components, contents, and value of each building (Section IV.E)
- Vulnerability data, expressed as fragility functions, that relate the anticipated building movements to damage in structural and nonstructural components and contents (Section IV.F)
- Consequence data that relates the anticipated damage in each building to repair costs, repair time, downtime, casualties, and contents losses (Section IV.G)

Section IV.A summarizes the general PSRA methodology, while Sections IV.B through IV.G describe the major inputs to the PSRA listed above. Section IV.H summarizes the primary outputs from the PSRA and provides a sample of the output.

A. Methodology

The probabilistic seismic risk assessment (PSRA) is based on the standard loss methodology outlined in **FEMA P-58** (2012b). FEMA P-58 represents the state-of-the-art in site-specific seismic risk assessment, drawing from over 10 years of research by FEMA. The FEMA P-58 methodology relates anticipated building movements (e.g., peak floor accelerations, drifts, and residual drifts) to damage of individual components (e.g., concrete walls, architectural glazing, water piping) and the associated consequences of this damage in terms of repair cost, repair time, and casualty rate.

The PSRA also leverages the REDi downtime assessment methodology (Arup 2013) as an overlay to the standard FEMA P-58 loss methodology. The REDi methodology converts repair times from FEMA P-58 into estimates of downtime through consideration of labor allocation, delays to initiation of repairs (i.e., impeding factors), and intermediate recovery states (i.e., re-occupancy and functional recovery) along the path to full recovery. The downtime estimates produced by REDi are expected to more realistically predict the duration of time a court building could be unusable following different earthquake intensities.

The consultant team developed probabilistic seismic risk models for each of the following scenarios:

- Current existing court building
- Baseline retrofit option (Option 1)
- Full renovation option (Option 3)

Risk models were not explicitly developed for the priority upgrades option (Option 2), the replace to 2016 CBC option (Option 4), or the replace to beyond code option (Option 5). For the priority upgrades option (Option 2), results from the risk model for the baseline retrofit option (Option 1) were leveraged due to similarities in expected seismic performance (i.e., the only difference between these two options is typically a small number of building system upgrades, which are not expected to impact seismic performance significantly). Refer to Sections IV.C and IV.E for additional discussion about the risk models for each retrofit option.

For the two replacement options (Options 4 and 5), risk models were not developed due to insufficient information about the design and configuration of these new facilities. Instead, for the replace to 2016 CBC option (Option 4), repair costs and downtime from the risk model for the full renovation option (Option 3) were scaled by a factor of 0.75. The consultant team selected this factor based on previous project experience and the fact that seismic retrofits typically are designed to approximately 75 percent of the seismic hazard of new code buildings, meaning that new buildings are stronger and would be expected to perform better than retrofitted buildings. While increased strength may not always translate into reduced repair costs and downtime, in the absence of information about the designs of the replacement court buildings, this approximation was judged to be appropriate for the purposes of this study.

For the replace to beyond code option (Option 5), repair costs and downtime from the risk model for the full renovation option (Option 3) were scaled by a factor of 0.25 because beyond-code buildings (e.g., those that achieve REDi Gold performance) are specifically designed to minimize damage, repair costs, and downtime. Typically, this is achieved through improved detailing of nonstructural elements or by seismically isolating the building, resulting in substantial reductions in repair costs and downtime, often for a small increase in initial construction costs.

For both Options 4 and 5, casualties were not modeled because the two replacement facilities are expected to have significantly improved seismic safety relative to the existing court building.

The risk models are used to predict the seismic performance of both the existing court building and the five retrofit and replacement options in terms of collapse probability, casualties, repair costs, and downtime. There is significant uncertainty in predicting these metrics. The PSRA addresses this uncertainty through Monte Carlo analysis, a process in which hundreds to thousands of simulations are performed to determine the range of possible outcomes. For each of the six earthquake intensities evaluated, one thousand Monte Carlo simulations were performed per building. Each realization corresponds to a specific earthquake scenario, from which the building movement is estimated and the associated risks are determined. Each individual simulation randomly draws slightly different values of each input variable from a probabilistic distribution that captures uncertainty in each input. Figure 3 and Figure 4 show how casualties, repair costs, and downtime are calculated for an individual realization.

B. Seismic Hazard Analyses

Seismic hazard is an important input to the PSRA, as the prediction of casualties, repair costs, downtime, and other outputs are sensitive to the anticipated intensity of earthquake shaking. The consultant team performed a simplified seismic hazard analysis for each court building. Because this study uses simplified structural analysis techniques (see Section IV.C), the primary output from each analysis is an estimate of the spectral acceleration at the fundamental period of the court building (for both existing and retrofitted configurations) for each of the six earthquake intensities considered in this study.

The seismic hazard analyses draw from the probabilistic seismic hazard assessment performed by the United States Geological Survey (USGS) as part of the 2014 update to the National Seismic Hazard Maps (Petersen et al. 2014). The consultant team obtained the seismic hazard at each of the six intensities in this study using the Java-based platform developed by USGS as part of the National Seismic Hazard Mapping Project (USGS, n.d.). There are some limitations in the characterization of the seismic hazard from published sources like USGS. Namely, it typically does not account for site-specific impacts, including important local effects (e.g., basin amplification) and nonlinear soil response, including liquefaction. Consequently, site-specific seismic hazard analyses would need to be performed as part of a detailed retrofit or replacement design for a court building.

The following sections provide additional explanation of how the seismic hazard (i.e., spectral acceleration) was determined for each court building.

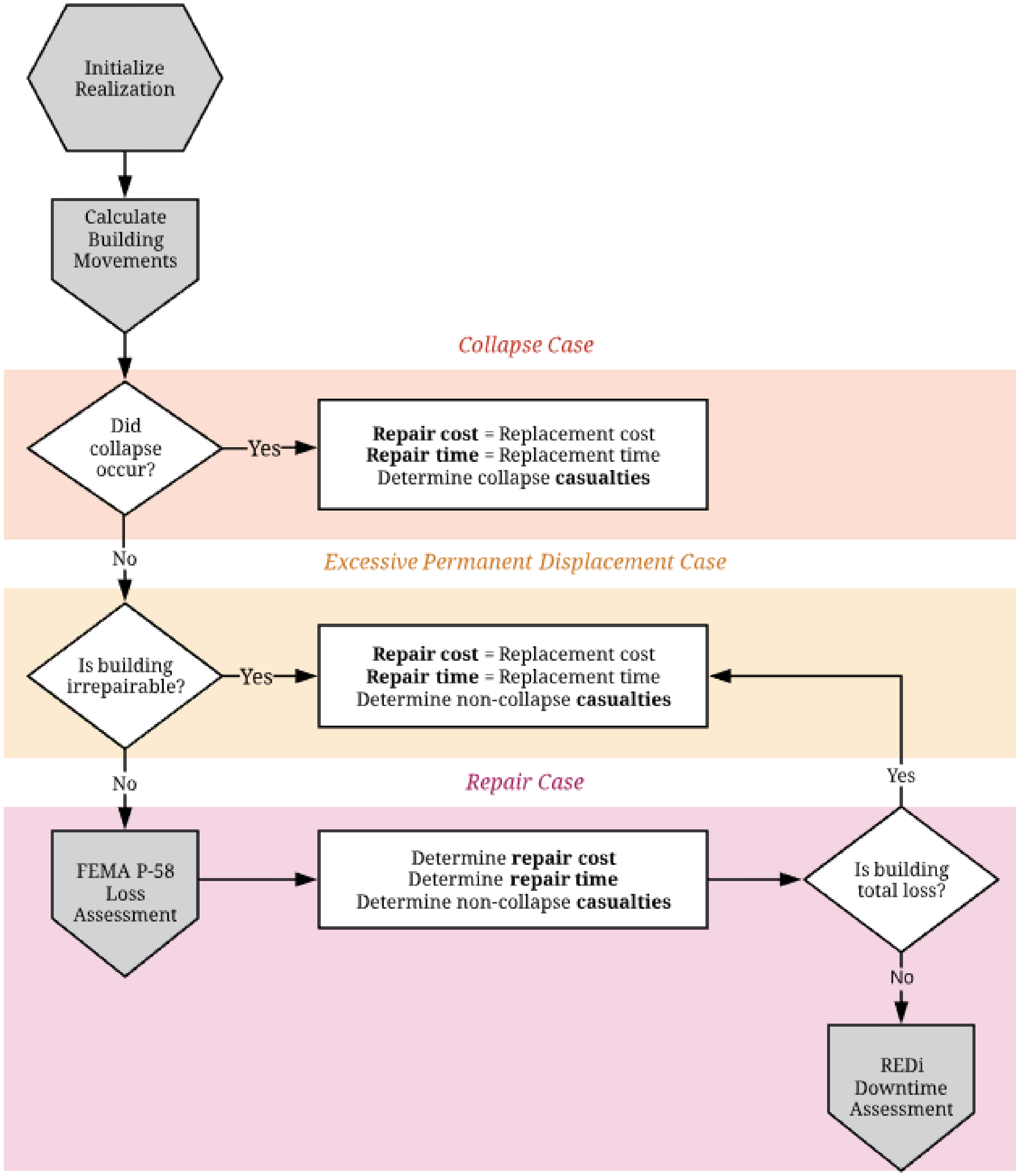

Figure 3. Overview of the PSRA Methodology Used in This Study

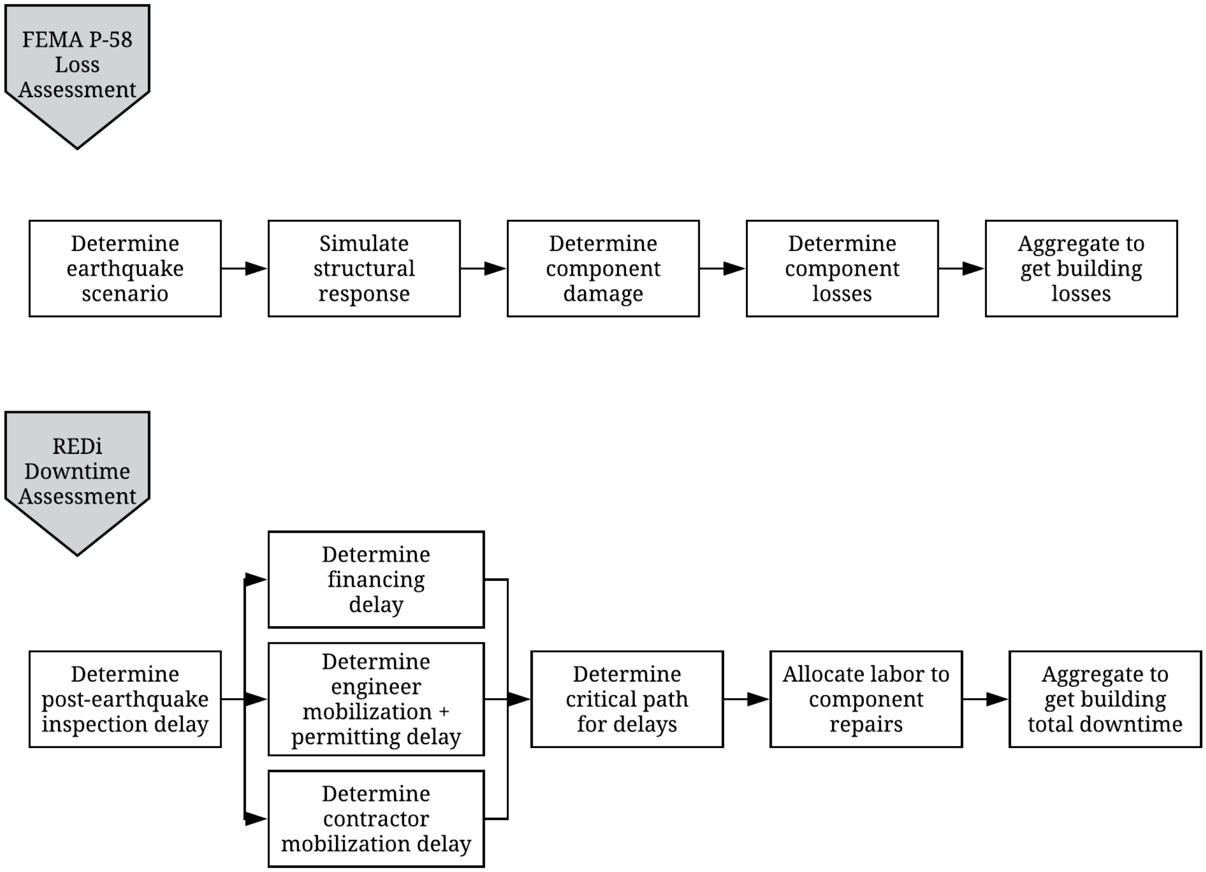

Figure 4. Overview of FEMA-P58 Loss Methodology (Top) and REDi Downtime Methodology (Bottom)

1. Soil Site Class

The soil conditions at a site can significantly influence the strength of earthquake ground shaking. Soil conditions can vary substantially from site to site, even for those close to each other. As such, the identification and characterization of the site soil conditions for each court building is an important input to the seismic hazard analysis.

In common seismic hazard assessment practice, the average shear wave velocity in the top 30 meters of soil ($V_{s,30}$) is used as a proxy to characterize how the site will respond in an earthquake. The sites considered in this study range from as soft as 600 ft/s (Site Class E) to as stiff as 5,000 ft/s (Site Class B) (ASCE 2014). Where possible, site class data was obtained from geotechnical reports referenced in the 2003 ASCE 31-03 Tier 1 or 2 seismic evaluation reports provided by the Judicial Council. However, there was a significant subset of court buildings for which such documentation was not available. In those cases, the soil site class was determined by averaging $V_{s,30}$ data from USGS. If $V_{s,30}$ data was not available, Site Class D was assumed.

Figure 5 shows a map of soil site class values for the 26 court buildings in this study. Stanley Mosk Courthouse (19-K1) is Site Class B but is obscured on the map due to the high density of court buildings in Los Angeles County. All but six court buildings are Site Class D.

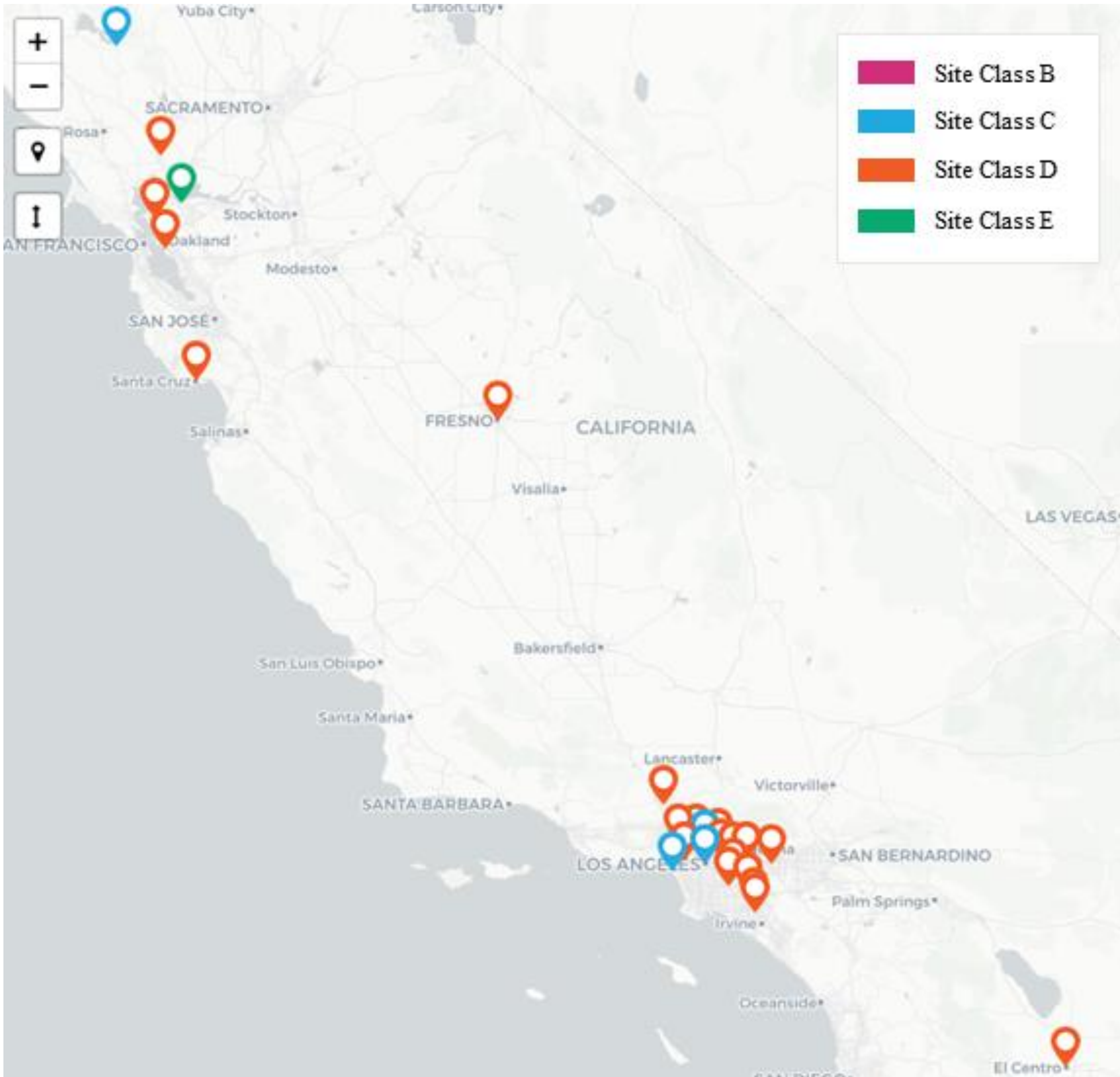

Figure 5. Map Showing Soil Site Class Values for 26 Court Buildings
Note: Stanley Mosk Courthouse (19-K1) is Site Class B but is obscured on the map due to the high density of court buildings in Los Angeles County.

2. Earthquake Intensity Levels

Table 5 presents the six earthquake intensity levels included in this study, spanning the range of frequent to very rare events. Six intensities were selected to ensure that the PSRA captured the full spectrum of damage to a court building, from minor or no damage at the 45-year earthquake intensity level to severe damage or even collapse at the 2,475-year level.

3. Uniform Hazard Spectra

For each earthquake intensity level and court building site, the consultant team determined the uniform hazard spectrum (UHS) using the 2014 update to the USGS National Seismic Hazard Maps (Petersen et al. 2014) and the assumed soil site class values. The UHS plots the spectral acceleration at a site as a function of fundamental building period for each earthquake intensity. Figure 6 shows the UHS for the Santa Monica Courthouse (19-AP1) as an example.

Table 5. Six Earthquake Intensities Levels Considered in the PSRA

Average return period (years)	Average annual rate (per year)	Probability in 30 years	Probability in 50 years
45	0.02222	49%	67%
100	0.01000	26%	39%
225	0.00444	12%	20%
475	0.00211	6%	10%
975	0.00103	3%	5%
2475	0.00040	1%	2%

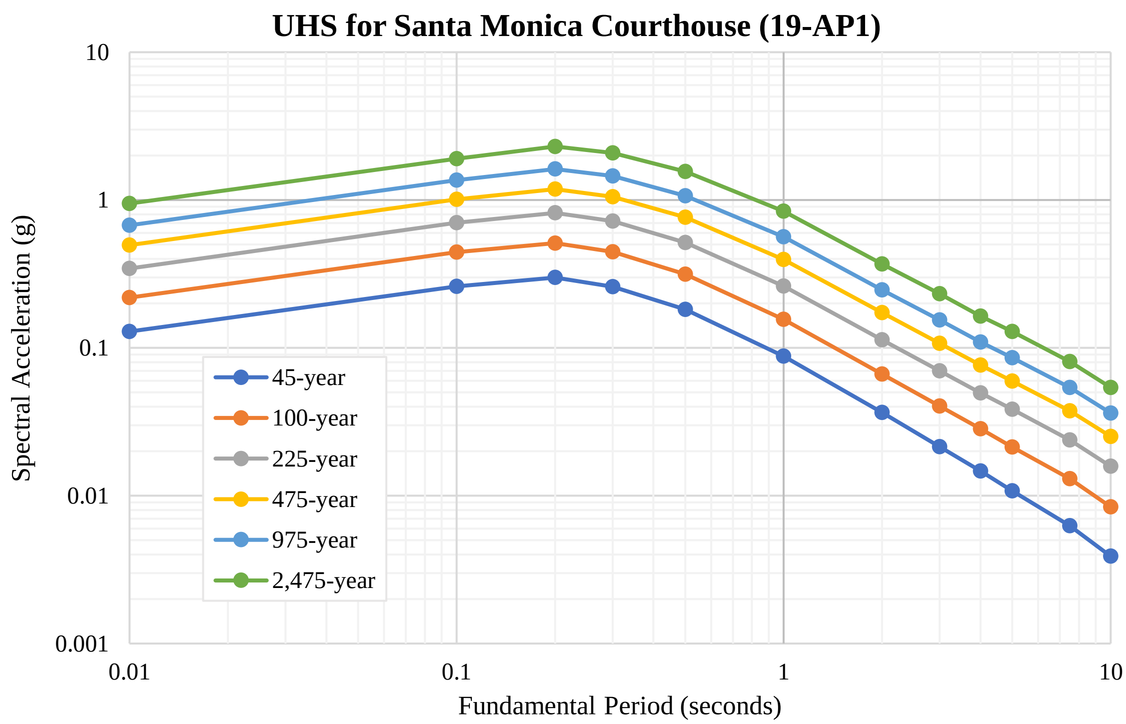

Figure 6. Uniform Hazard Spectra (UHS) for the Santa Monica Courthouse

4. Spectral Acceleration

Using the UHS for each site and the fundamental period of the existing court building or retrofit option, the consultant team determined the spectral acceleration at each earthquake intensity. This is a primary input to the simplified structural analysis of each court building, which is described in Section IV.C.

Per Section IV.A, three risk models were developed for each court building: the current existing court building, the baseline retrofit option, and the full renovation option. Consequently, the fundamental period needs to be determined for each model. The consultant team used Equation 12.8-7 of ASCE 7-10 (2013) to calculate the approximate fundamental period for the two retrofit models (see Equation 1 below). The two coefficients in Equation 1, C_t and x, were determined from the structure type of the retrofitted court building. For example, for concrete shear wall structures, $C_t = 0.02$ and $x = 0.75$ per Table 12.8-2 in ASCE 7-10. The period estimate from this equation represents a lower bound on the fundamental period for the retrofit. Lower bound period estimates are used in design because they tend to produce conservative estimates of the seismic demand (i.e., shorter periods have higher spectral accelerations, as illustrated in Figure 6).

$$T_a = C_t h_n^x \qquad \text{Equation 1}$$

Where:

T_a	= approximate fundamental period
h_n	= structural height
C_t, x	= coefficients based on structure type; refer to Table 12.8-2 in ASCE 7-10 (2013) for coefficient values

For existing court buildings, the consultant team attempted to determine more realistic estimates of fundamental period. While detailed structural analyses were not performed in this study (which would have produced the most accurate estimates of period), the consultant team leveraged the provision in ASCE 7-10 that limits the fundamental period to T_a (from Equation 1) multiplied by C_u, the coefficient for upper limit on calculated period. A value of 1.5 was assumed for C_u in this study. In the experience of the consultant team, the limit on the fundamental period (i.e., $T_a \times C_u$) would likely be exceeded if a more detailed structural model were developed, meaning the cap is an appropriate estimate of the fundamental period of the existing court building for this study. The consultant team judged the longer period of the existing facility to be appropriate given the fact that a seismic retrofit typically stiffens a structure. Also, older buildings tend to be less stiff than modern code-compliant ones.

5. Liquefaction

Liquefaction is a phenomenon in which earthquake ground shaking produces excess pore pressure and causes a subsequent loss of soil strength, resulting in significant lateral displacement or uneven vertical settlement of a building. This behavior is a concern for structures with shallow foundations in loose, saturated soils, such as clays or sands below the water table.

Though not explicitly considered in the PSRA, the consultant team estimated the liquefaction susceptibility for each court building using data from previous liquefaction studies by the USGS and California Geological Survey (USGS 2000, USGS 2006, Jones et al. 2008). Figure 7 shows the liquefaction susceptibility values for the 26 court buildings in this study. These values are provided for information purposes only — a site-specific geotechnical evaluation would be required to verify liquefaction susceptibility at each court building as part of a detailed retrofit or replacement design.

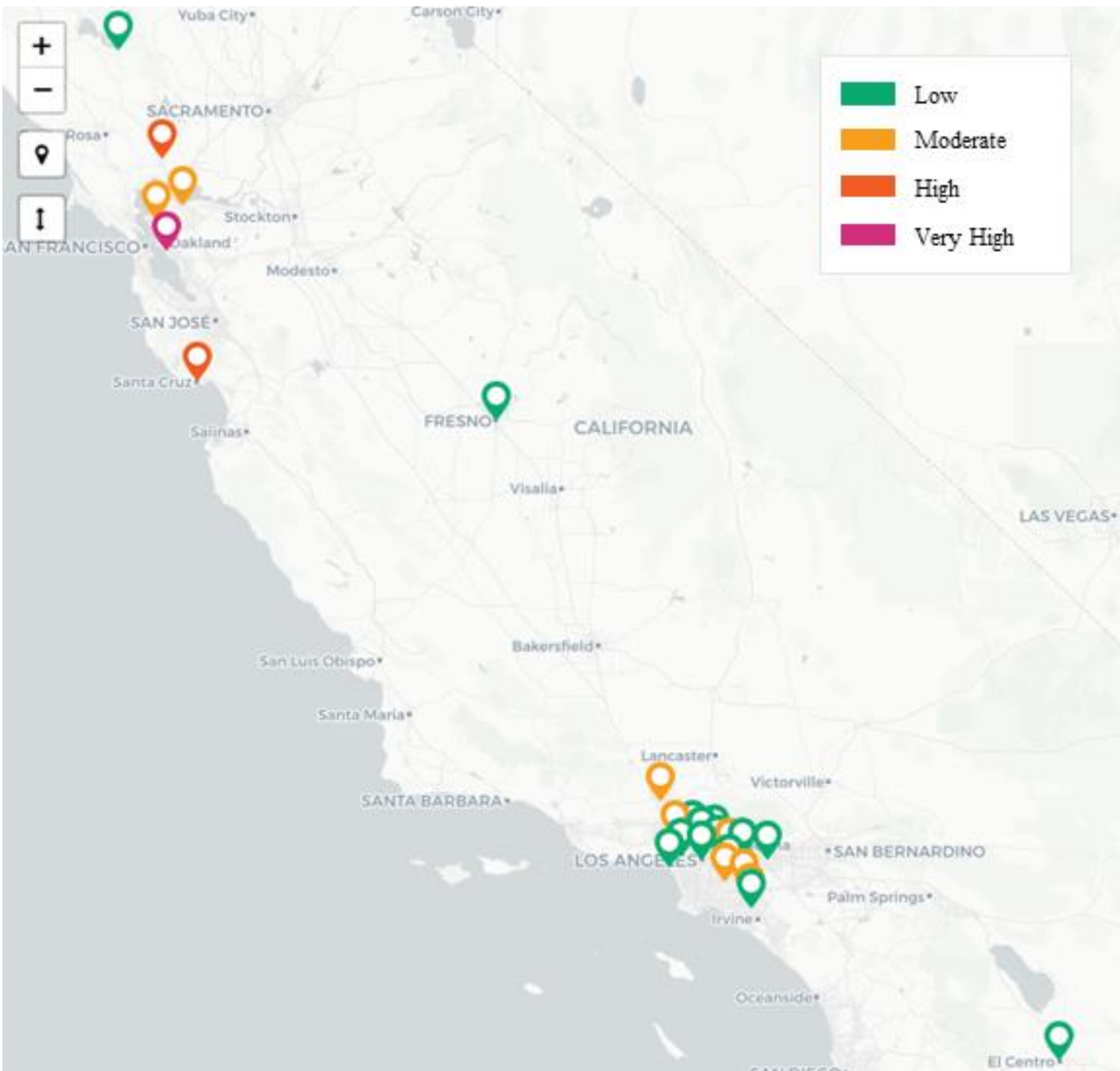

Figure 7. Map Showing Liquefaction Susceptibility Values for 26 Court Buildings

C. Simplified Structural Analysis

Using outputs from the seismic hazard analysis, the consultant team performed simplified structural analyses of each court building and retrofit scheme to estimate important engineering demand parameters (EDPs) for the PSRA. EDPs capture the building movements (e.g., interstory drift ratio, floor acceleration) caused by an earthquake. Table 6 lists the EDPs and calculation methods used in this study.

Table 6. Engineering Demand Parameters (EDPs) Calculated from the Simplified Structural Analysis

EDP	Calculation Method	Additional Discussion
Peak interstory drift ratio	Miranda (1999) and FEMA P-58 Simplified Analysis Procedure (2012b)	Section IV.C.1
Peak floor acceleration	FEMA P-58 Simplified Analysis Procedure (2012b)	Section IV.C.2
Residual interstory drift ratio	FEMA P-58 Simplified Analysis Procedure (2012b)	Section IV.C.3

The methodology was largely adopted from the FEMA P-58 Simplified Analysis Procedure (2012b), which enables the estimation of important EDPs using relatively limited building information and seismic hazard characterized by spectral acceleration. While some of the limitations of the simplified procedure were exceeded for some court buildings (i.e., those with more than 15 stories or irregular plans or elevations), detailed structural analyses were not possible given the high-level nature of the supplemental ASCE 41-13 Tier 1 evaluations and the conceptual nature of the retrofit schemes. Consequently, the consultant team judged the FEMA P-58 simplified procedure to be appropriate for this study, capturing the expected seismic response of the court buildings at a high level.

Inputs to the simplified structural analysis are based largely on non-detailed evaluations, including rapid visual screening and simple calculations based on available structural drawings or knowledge of historical building codes in California. Consequently, the simplified analysis is unable to capture building-specific deficiencies such as setbacks and vertical offsets and is not a substitute for detailed structural analysis.

The EDPs from the simplified structural analyses are assumed to be the best estimate (i.e., median) values. In computing these quantities, variability is applied to account for significant uncertainty in the analyses, including the completeness of the analytical models and as-built construction documents. This variability, referred to as the modeling dispersion, is described in more detail in Chapter 5 of FEMA P-58 (2012b). Per recommendations in FEMA P-58, the consultant team used a modeling dispersion value of 0.5 (the maximum value possible) for all court buildings to account for the simplified nature of the analysis (including the fact that some of the limitations of the simplified procedure that were exceeded) and the lack of consistency in drawing quality. In future studies, the modeling dispersion can be reduced by increasing the sophistication of the structural analysis.

The following sections describe how each of the EDPs in Table 6 is calculated.

1. Peak Interstory Drift Ratio

The FEMA P-58 Simplified Analysis Procedure (2012b) outlines a methodology for estimating peak interstory drift ratios (IDRs). However, the methodology requires development of a 3-D linear elastic building model to estimate elastic deformations, which is beyond the scope of this study. Consequently, the consultant team used an alternate method described by Miranda (1999) to estimate elastic deformations. In overview, Miranda proposes an equivalent continuum model to estimate elastic deformations of multi-story buildings using simplified inputs, including fundamental period, structural behavior type (i.e., shear, flexural, or combined), lateral load distribution shape, floor heights and weights, yield strength, and yield drift ratio. Table 7 summarizes how each of these inputs is calculated.

Table 7. Summary of Inputs Required for Equivalent Continuum Model Proposed by Miranda (1999)

Input	Calculation Method
Fundamental period	Calculated using the procedure described in Section IV.B.4
Structural behavior type	Assigned based on existing building drawings and the following mapping: • Wall buildings: shear behavior • Frame buildings: flexural behavior • Other buildings (including braced frame): combined behavior
Lateral load distribution shape	Triangular
Floor heights and weights	Obtained or calculated from existing building drawings
Yield strength	Calculated from existing building drawings or conceptual retrofit scheme
Yield drift ratio	Based on previous project experience and simplified elastic models using structural analysis software (e.g., Oasys GSA)

Assumptions implicit in the application of Miranda (1999) include uniform mass and stiffness distribution over the height of the building and lateral displacements approximated by the first mode contribution. These assumptions were found to be reasonable for the objectives of this study, but further detailed analysis would be necessary to increase the confidence level in the EDPs for each building.

Elastic deformations from the equivalent continuum models are then adjusted using various correction factors to obtain peak IDRs using the FEMA P-58 Simplified Analysis Procedure. Refer to FEMA P-58 for more information (2012b).

2. Peak Floor Acceleration

The consultant team used the FEMA P-58 Simplified Analysis Procedure without modification to calculate peak floor accelerations. Primary inputs to this calculation include the peak ground acceleration, fundamental period of the structure, yield strength, and spectral acceleration at the fundamental mode. Calculation of the fundamental period and yield strength are described in Table 7, while the peak ground acceleration and spectral acceleration at the fundamental period are outputs of the seismic hazard analysis (refer to Section IV.B). The peak ground acceleration is then adjusted using various correction factors to obtain peak floor accelerations throughout the structure.

3. Residual Interstory Drift Ratio

Using peak IDRs and the yield drift ratio, the FEMA P-58 Simplified Analysis Procedure proposes a simple equation to estimate the residual IDRs, as shown in Equation 2.

$$\Delta_r = \begin{cases} 0, & \Delta \leq \Delta_y \\ 0.3(\Delta - \Delta_y), & \Delta_y < \Delta < 4\Delta_y \\ \Delta - 3\Delta_y, & \Delta \geq 4\Delta_y \end{cases} \qquad \text{Equation 2}$$

Where:

Δ = Peak interstory drift ratio

Δ_r = Residual interstory drift ratio

Δ_y = Yield drift ratio

The yield drift ratio is based on previous project experience and simplified elastic models using structural analysis software (e.g., Oasys GSA).

D. Collapse Fragilities

The probability of collapse is an important input to the PSRA because of the large number of casualties and significant financial losses that collapse can generate. The consultant team developed collapse fragilities for each court building and retrofit scheme. A collapse fragility relates the probability of collapse to the intensity of earthquake ground shaking, typically characterized by the spectral acceleration at the fundamental building period. Figure 8 shows sample collapse fragilities for the Clara Shortridge Foltz Criminal Justice Center (19-L1), for both the current existing court building and the conceptual retrofit scheme. Because the seismic upgrades to the structure are the same across retrofit options 1, 2, and 3, the collapse fragility is equivalent for each option.

To determine collapse fragilities for existing court buildings, the consultant team leveraged the seismic risk ratings (SRRs) developed by R+C from their 2017 study of Risk Level V court buildings for the Judicial Council (R+C 2017). The SRRs, which were computed using the Hazus Advanced Engineering Building Module (FEMA 2013b), measure the relative probability of collapse in the BSE-2E as defined in ASCE 41-13 (2014). Equation 3 provides the formula for computing the SRR (from R+C 2017).

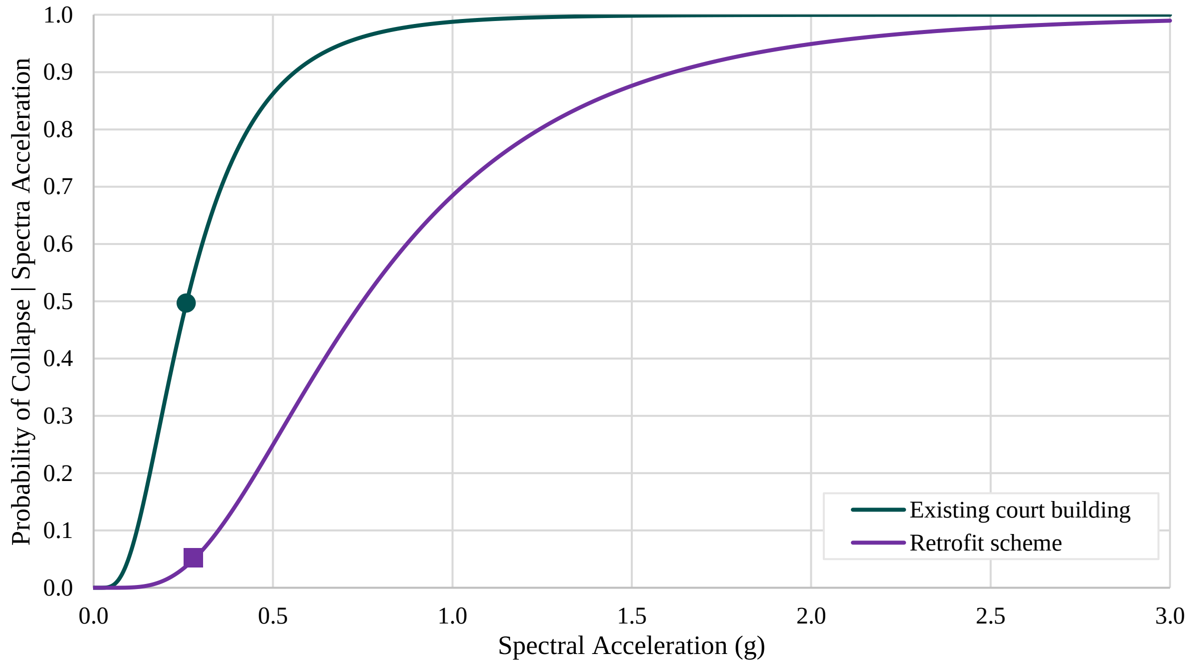

Figure 8. Collapse Fragilities for the Clara Shortridge Foltz Criminal Justice Center (19-L1)

$$SRR = P(COL|STR_5) \times P(STR_5) \quad \text{Equation 3}$$

Where:

$P(COL\|STR_5)$	= Collapse factor of the Hazus Advanced Engineering Building Module
$P(STR_5)$	= Probability of complete structural damage, based on Hazus Advanced Engineering Building Module methods and parameters

Per Equation 3, the SRR indicates the portion of the total building area that has collapsed; however, this definition of collapse differs from those implicit to ASCE 41-13 and ASCE 7-10, which define collapse more broadly to include complete collapse, partial collapse, and near collapse scenarios. Therefore, the consultant team established a method for modifying the SRRs to be consistent with the code definition of collapse, as detailed below.

The consultant team used $P(STR_5)$, the probability of complete structural damage, as the probability of collapse for a court building because its definition (refer to FEMA 2013a for definitions for common building types) was judged to more closely align with the definition of collapse implied in modern building codes. The consultant team established a minimum threshold of 20 percent for $P(STR_5)$, as lower values were judged to not accurately represent the collapse risk because the court buildings all have significant seismic vulnerabilities. This single point, illustrated in Figure 8 as a green circle, was used to anchor the collapse fragility curve for an existing court building. The fragility curve has lognormal distribution and dispersion of 0.6 per the standard collapse fragility curve in ASCE 7-10 (2013).

To determine collapse fragilities for the conceptual retrofit schemes, the consultant team used implicit performance objectives in ASCE 7-10 to estimate the probability of collapse of a retrofitted building in the BSE-2E. ASCE 7-10 targets a collapse probability of approximately 10 percent in the BSE-2N for new buildings. Using this target as a guide, the consultant team assumed a 5 percent collapse probability for retrofitted buildings in the BSE-2E. This value reflects conservatisms in the retrofit process that would likely reduce the collapse probability to less than 10 percent. This single point, illustrated in Figure 8 with a purple square, was used to anchor the collapse fragility curve for retrofitted buildings. The fragility curve has lognormal distribution and dispersion of 0.6 per the standard collapse fragility curve in ASCE 7-10 (2013).

Collapse fragilities for replacement court buildings were not developed due to significant improvements in the seismic safety of new, code-compliant buildings relative to existing court buildings, which are typically over 30 years old and have significant seismic vulnerabilities. Consequently, the collapse probability of a replacement court building is taken as less than 1 percent across the range of earthquake intensities considered in this study. While new buildings are designed to have approximately 10 percent probability of collapse in the BSE-2N, new court buildings are expected to perform much better than this because they must satisfy the more stringent requirements of Risk Category III structures.

Collapse fragilities are the primary input in computing fatalities in the PSRA. However, there is significant variability in the range of outcomes within the complete structural damage state. For example, for concrete shear wall buildings (i.e., C2 buildings), complete structural damage is defined as follows: "Structure has collapsed or is in imminent danger of collapse due to failure of most of the shear walls and failure of some critical beams or columns. Approximately 13 percent (low-rise), 10 percent (mid-rise) or 5 percent (high-rise) of the total area of C2 buildings with complete damage is expected to be collapsed" (FEMA 2013a). To account for this variability, a factor of 0.15 was applied across all buildings when computing fatalities in realizations where collapse had occurred (see Figure 3). Refer to Section IV.G.3 for additional discussion of the fatality rate.

E. Exposure Data

Exposure data refers to the inventory of assets in a building, including structural components, nonstructural components, building contents, and building populations. These assets can be damaged, destroyed, or, in the case of people, injured or killed by an earthquake. The PSRA requires a comprehensive inventory of significant assets in a building to ensure that predicted casualties, repair costs, and downtime are representative of the assets at risk.

The consultant team developed inventories of structural and nonstructural components for each court building from existing building drawings, on-site evaluations, and normative quantities from FEMA P-58 (2012b). The process for developing these inventories is detailed in Section IV.E.1. Building populations and replacement costs were provided by the Judicial Council and are described in Sections IV.E.2 and IV.E.3, respectively.

1. Inventory of Structural and Nonstructural Components

The consultant team developed inventories of structural components for each existing court building using information from existing building drawings, including (but not limited to) floor areas, plan dimensions, structural system configuration, number of columns or braces, and length of structural wall. For buildings with incomplete drawings, on-site evaluations and estimated floor areas guided the estimation of structural component quantities. The consultant team used drawings and descriptions of the conceptual retrofit schemes to determine changes in quantities of structural components for the baseline retrofit and full renovation risk models.

The consultant team developed inventories of nonstructural components using existing building drawings and normative quantities from FEMA P-58. Normative quantities are estimates of the quantities of nonstructural components and contents likely to be present in a building of a specific occupancy on a gross square foot basis (FEMA 2012b). FEMA developed normative quantities for different occupancies (e.g., commercial office, healthcare, residential, retail) based on surveys of various construction types, occupancy types, and floor areas. For this study, the commercial office occupancy was judged to be most similar to a typical court building; therefore, normative quantities for commercial office were used to estimate quantities of most nonstructural components. Table 8 documents the quantities of nonstructural components included in each of the three seismic risk models developed for each court building.

Table 8. Quantities of Nonstructural Components Included in Each Seismic Risk Model (Normative quantities for commercial office are assumed.)

Component	Existing Court Building	Baseline and Priority Upgrades Options (Options 1 and 2)	Full Renovation Option (Option 3)
Cladding	Use satellite imagery, drawings, photos, field notes	Use retrofit drawings to determine percentage replaced	Replace 100 percent
Roof tiles	Not included		
Interior partitions	Use 90th percentile normative quantities		
Ceramic wall tiles	Not included		
High end marble or wood panel	Not included		
Ceramic tile floors	Not included		
Vinyl/carpet floor finishes	Use floor areas		
Raised access floors	Not included		
Ceilings	Use 50th percentile normative quantities		
Stairs	Determine from drawings		
Elevators	Determine from drawings		

Component	Existing Court Building	Baseline and Priority Upgrades Options (Options 1 and 2)	Full Renovation Option (Option 3)
Plumbing (pipes and bracing)	Use 50^{th} percentile normative quantities		
Mechanical/HVAC equipment	Use 50^{th} percentile normative quantities		
HVAC ducting	Use 50^{th} percentile normative quantities		
Electrical equipment	Use 50^{th} percentile normative quantities		
Pendant lighting	Use 50^{th} percentile normative quantities (half to pendant lighting)		
Recessed lighting	Use 50^{th} percentile normative quantities (half to recessed lighting)		
Fire sprinkler piping	Determine presence of sprinklers from survey; if fully sprinkled, use 50^{th} percentile normative quantities, otherwise do not include		Use 50^{th} percentile normative quantities
Fire sprinkler drops	Determine presence of sprinklers from survey; if fully sprinkled, use 50^{th} percentile normative quantities, otherwise do not include		Use 50^{th} percentile normative quantities

2. Population Data

To calculate casualty rates from building damage and collapse, population models are required to estimate the number of people in each court building. Peak populations can be used for FEMA P-58 risk assessments, resulting in conservative estimates of casualties. However, peak populations persist within buildings for only short periods of time, with building populations varying drastically due to hourly, daily, and monthly fluctuations. To account for the movement of populations within each building over time, an equivalent continuous occupancy can be calculated to obtain an averaged building population at any given time.

For this study, peak populations are used in the PSRA to obtain an upper bound on the number of casualties at each court building and earthquake intensity level (refer to Section V.E for findings from a sensitivity study in which building populations were changed from peak to ECO). The Judicial Council provided population data for each court building in the form of average total number of daily visitors and staff (excluding judges) from magnetometer data. This includes all visitors, whether they stay for an hour or the entire day, and thus may overestimate the peak population. However, for very busy days (such as Mondays), the peak instantaneous population is higher than other days, and thus may be close to the average total population. In the absence of better data, the average total number of daily visitors and staff is considered to be equivalent to the peak instantaneous population of the building.

3. Building Replacement Values

Replacement values for court buildings are derived from a cost-model database of construction costs for California Superior Court buildings of similar scope and location that were constructed in the past 10 years. This cost-model database was provided by the Judicial Council. Replacement values are in 2018 dollars and exclude costs for demolition, escalation, design and engineering consultant fees, loose furniture, fixtures, and equipment, and construction and owner contingencies. The replacement value of the court building represents the direct financial loss if the structure collapses or is damaged beyond repair, which is assumed to occur if repair costs exceed 40 percent of the replacement value.

F. Vulnerability Data

The likelihood of damage for various components is modeled using fragility functions. A fragility function relates the probability of being in a particular damage state (e.g., aesthetic or life-safety critical) to an engineering demand parameter (EDP) such as interstory drift ratio (IDR) or peak floor acceleration. Certain building components are sensitive to IDR (e.g., interior gypsum partition walls, steel moment frames), while others are sensitive to peak floor acceleration (e.g., suspended ceilings, motor control centers). A sample fragility curve for partial-height gypsum partition walls is shown in Figure 9 as a function of IDR. As illustrated by the colored regions, at increasing levels of drift, the likelihood of being in a more severe damage state increases.

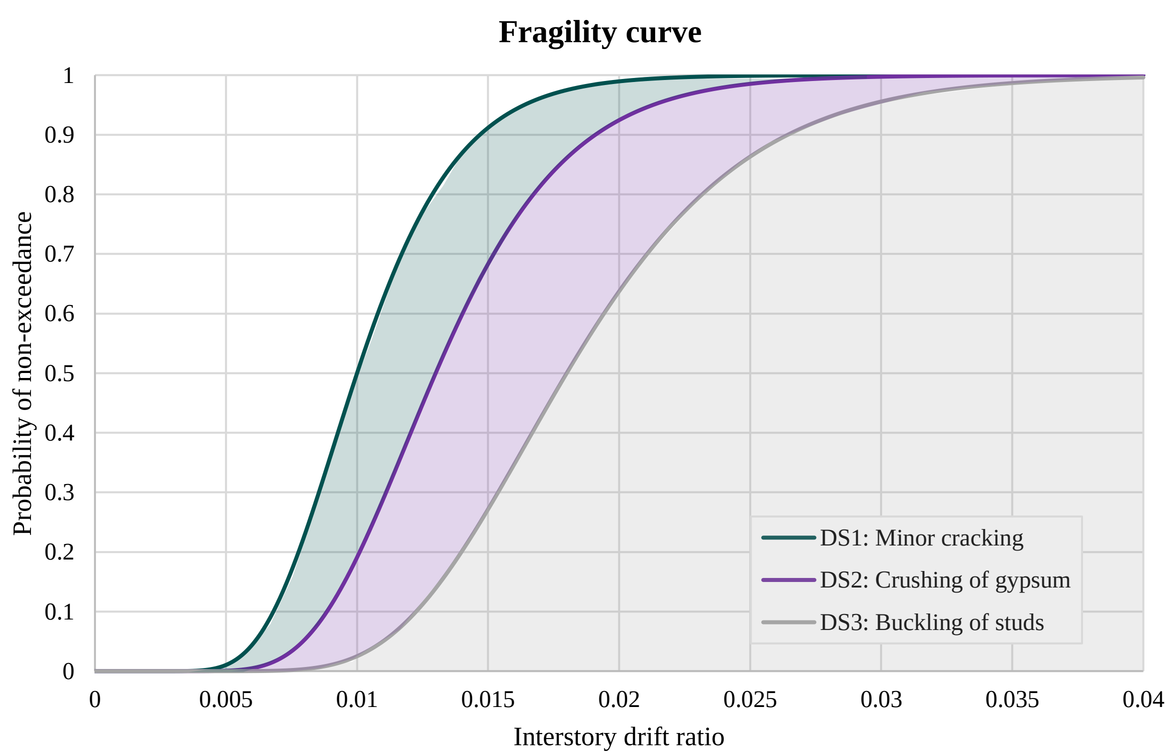

Figure 9. Sample Fragility Function for Partial-Height Gypsum Partition Walls (FEMA 2012b)

FEMA P-58 provides a large library of fragility functions for both structural and nonstructural components. These fragility functions were developed by various researchers, often by compiling data from dynamic or quasi-static testing, or from observations during past earthquakes. In some cases, fragility functions are based on expert opinion.

Table 9 lists the fragility functions chosen for the nonstructural components in each of the three seismic risk models. Refer to Table 8 for the corresponding quantities of nonstructural components in each risk model. In general, nonstructural components in existing court buildings were modeled with fragility functions lacking seismic detailing due to the old ages of the court buildings (all are at least 30 years old). For the baseline retrofit risk models, a limited number of structural and nonstructural components (e.g., cladding, ceilings, stairs, elevators) were replaced per the retrofit drawings, with the fragility functions for these components reflecting new construction with proper seismic detailing. For the full renovation risk model, all nonstructural components were modeled with fragility functions having proper seismic detailing because the building interior is demolished and replaced.

Table 9. Fragility Functions for Nonstructural Components Included in Each Seismic Risk Model

Component	Existing Court Building	Baseline and Priority Upgrades Options (Options 1 and 2)	Full Renovation Option (Option 3)
Cladding	Determine fragility from drawings and satellite imagery	For replacement cladding, use fragility for modern curtain wall, for existing cladding, determine fragility from drawings and satellite imagery	Use fragility for modern curtain wall
Roof tiles	Not included		
Interior partitions	Use fragility for full height partitions (fixed above and below)		
Ceramic wall tiles	Not included		
High end marble or wood panel	Not included		
Ceramic tile floors	Not included		
Vinyl/carpet floor finishes	Use fragility for weakest pipe (per FEMA P-58)		
Raised access floors	Not included		
Ceilings	Use fragility for SDC A/B/C (vertical support only)	Use 25% SDC A/B/C (vertical support only) and 75% SDC D/E (vertical and lateral support)	Use fragility for SDC D/E (vertical and lateral support)
Stairs	Use fragility without seismic joint	If stairs replaced, use fragility with seismic joint, otherwise use fragility without seismic joint	Use fragility with seismic joint

Component	Existing Court Building	Baseline and Priority Upgrades Options (Options 1 and 2)	Full Renovation Option (Option 3)
Elevators	If elevator not modernized, use fragility for pre-1976 installation, otherwise use fragility for post-1976 installation	Use fragility for post-1976 installation	
Plumbing (pipes and bracing)	Use fragility for SDC A/B/C		Use fragility for SDC D/E/F
Mechanical/HVAC equipment	Use fragility for hard anchored or vibration isolated equipment		
HVAC ducting	Use fragility for SDC A/B/C		Use fragility for SDC D/E/F
Electrical equipment	Use fragility for hard anchored or vibration isolated equipment		
Pendant lighting	Use fragility for non-seismic installation		Use fragility for seismically rated installation
Recessed lighting	Use fragility for lighting with independent support wires		
Fire sprinkler piping	If fully sprinkled, use fragility with no bracing	If fully sprinkled, use fragility with designed bracing	Use fragility with designed bracing
Fire sprinkler drops	If fully sprinkled, use fragility for dropping into unbraced lay-in tile	If fully sprinkled, use fragility for dropping into braced lay-in tile	Use fragility for dropping into braced lay-in tile

G. Consequence Data

Consequences associated with component damage or building failure include casualties, repair costs, and downtime. Baseline values for repair costs, repair times, and casualty rates for each damage state for each building component were obtained from the FEMA P-58 database (FEMA 2012b).

1. Repair Costs

FEMA P-58 provides repair procedures and associated repair costs for each damage state of each structural and nonstructural component. FEMA P-58 repair costs are calculated in 2011 dollars, based on Northern California labor rates. To account for inflation and escalation between 2011 and 2018, the consultant team used factors of 1.11 and 1.25, respectively, resulting in a time factor of 1.39 to convert repair costs to 2018 dollars. Labor rates were assumed to be similar between Northern and Southern California. Contents losses (e.g., furniture, computers) were not considered.

For earthquake simulations that result in a total loss, the repair costs are equivalent to the total building replacement value plus demolition costs, which are assumed to be 5 percent of the total replacement value. Construction of the replacement facility is assumed to take 4 years. A building is considered a total loss and subsequently demolished and replaced if any of the following conditions apply:

- The building has collapsed, either locally or globally.
- The building has significant permanent displacement (i.e., residual drift) after an earthquake. Heavy structures such as concrete are especially vulnerable to demolition due to permanent displacement, whereas lighter structures might be more economical to be put back in plumb. A default demolition fragility curve was developed based on Ramirez and Miranda (2012).
- It is uneconomical to repair. This occurs if the aggregate repair cost exceeds 40 percent of the total building replacement value, as recommended by FEMA P-58.

2. Downtime

Downtime is calculated using the REDi downtime methodology (Arup 2013) with unpublished enhancements used for this study. The REDi methodology uses FEMA P-58 repair times to calculate downtime. Downtime refers to the time required to restore building functionality after an earthquake. Unlike FEMA P-58 repair times, downtime includes potential delays to the initiation of repairs, resulting in a more realistic estimation of duration of loss of functionality.

The first step in calculating downtime involves determining whether the extent and severity of damage to specific components warrants closure of the building (i.e., a yellow or red tag due to a life-safety risk) or renders it unusable (e.g., damage to equipment hinders functionality of lighting or ventilation). This mapping is accomplished through use of repair classes, which determine if a damaged component would hinder reoccupancy or functionality. For each earthquake realization, each building component is assigned a repair class based on the extent and severity of damage and the criticality of the component. Some modifications were made to the default repair class assumptions in Arup (2013) based on improved knowledge. These are summarized in Table 10.

Table 10. Summary of Changes to Repair Class Assignments from Those Published in Arup (2013)

Component	Damage Description	Modified Repair Class	Basis
Anchored equipment	Anchorage failure	Repair Class 1 (hinders full recovery)	Equipment overturning or other falling hazards do not represent a persistent life-safety risk and thus would not likely result in yellow or red-tagging of a building (i.e., it would not trigger Repair Class 3). Any associated casualty rate is explicitly accounted for in the risk assessment.
Anchored equipment	Equipment failure	Repair Class 2 (hinders functional recovery)	
Unanchored equipment	Equipment failure due to overturning	Repair Class 2 (hinders functional recovery)	
Lighting fixtures	Disassembly of rod system at connections, fatigue failure, pullout of rods from ceiling	Repair Class 2 (hinders functional recovery)	

The next step in calculating downtime involves developing repair sequence logic that accounts for delays to the initiation of repairs. These delays, which are referred to as impeding factors, include post-earthquake inspection, financing, engineer mobilization, permitting, and contractor mobilization. These delays can be significant, and for low to moderate amounts of building damage can dominate the overall building downtime. Figure 10 shows the repair sequence logic (including impeding factors) described in Arup (2013).

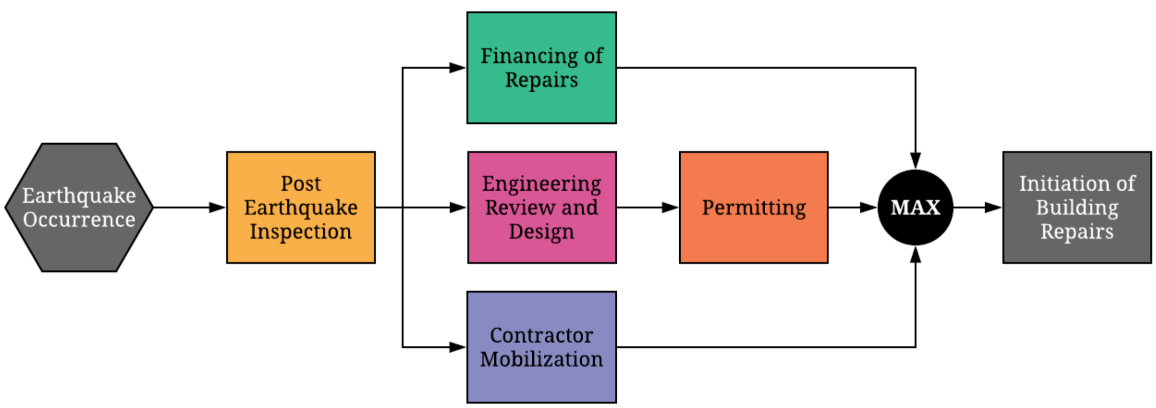

Figure 10. Repair Sequence Logic (Including Impeding Factors) for Calculating Downtime (from Arup 2013)

Table 11 summarizes the values for different impeding factors used in the study. Default values published in Arup (2013) were used for inspection, financing, engineering mobilization, and permitting. In contrast, contractor mobilization was modified to include improved data from previous projects and research efforts, including a survey of contractors and subcontractors to estimate the number of weeks required to procure materials and equipment and mobilize labor for different types of repairs. Contractor mobilization times also account for the scarcity of contractors in the aftermath of a large earthquake, and for the time required for the bidding and procurement process.

Table 11. Summary of Impeding Factors as a Function of Building Damage

Impeding factor	Component	Delay associated with aesthetic damage	Delay associated with functional or life-safety damage
Inspection	All	5 days	
Financing	All	15 weeks	
Engineering mobilization	Structural	6 weeks	12 weeks
Permitting	All	1 week	8 weeks
Contractor mobilization	Structural	14 weeks	22 weeks
	Architectural	7 weeks	18 weeks
	Exterior cladding	13 weeks	21 weeks
	Mechanical	12 weeks	19 weeks
	Electrical	9 weeks	11 weeks
	Elevators	19 weeks	28 weeks
	Stairs	8 weeks	17 weeks

3. Casualty Rates

Casualty rates (which includes both injuries and fatalities) for damaged structural and nonstructural components (which do not result in building collapse) were taken directly from the FEMA P-58 database. However, casualties tend to be dominated by building collapse as opposed to component-related damage in earthquakes. Thus, an assumption had to be made regarding the casualty rate for collapsed portions of a structure. Because of the heavy nature of most court buildings, a fatality rate of 100 percent was assumed in areas of collapse. Recall that in the event of building collapse, 15 percent of the total building area was assumed to have collapsed (see Section IV.D).

H. PSRA Outputs

The outputs of the PSRA include estimates of casualties, repair costs, and downtime for each court building (including each retrofit and replacement option) at the six earthquake intensities considered in this study. The predicted losses at each intensity can be converted into annualized losses using the annual recurrence of each seismic intensity. Annualized losses represent the anticipated seismic losses in any given year, and typically would not be incurred every year (i.e., in most years, there are no earthquakes and therefore no losses; however, if a significant earthquake occurs, the losses that year will greatly exceed the annualized losses). Over a long period of time, the actual losses incurred would approach the anticipated annualized losses. Though abstract in nature, annualized losses are useful because they capture in a single metric the magnitude of losses across a range of seismic intensities, thus enabling the risk reduction potential of each retrofit and replacement option to be compared more readily.

Table 12 provides annualized losses for each of the 26 court buildings and the selected retrofit or replacement options. Refer to Section V.B for more information about how annualized losses are computed.

Table 12. Annualized Losses for the Portfolio of 26 Court Buildings

County	ID	Name	Selected option*	Annualized loss ($thousands)					
				Existing court building			Selected option		
				F†	RC‡	DT**	F†	RC‡	DT**
Alameda	01-F1	George E. McDonald Hall of Justice	2	2,276	141	112	115	29	73
Contra Costa	07-A2	Wakefield Taylor Courthouse	2	3,353	624	430	1,422	184	409
	07-F1	George D. Carroll Courthouse	4	9,910	406	383	NS††	86	304
Fresno	10-A1	Fresno County Courthouse	1	11,405	204	325	4,697	100	281
Imperial	13-A1	Imperial County Courthouse	4	19,637	1,193	513	NS††	71	238
Lake	17-B1	Clearlake Branch Courthouse	4	1,221	29	42	NS††	4	15
Los Angeles	19-AD1	Santa Clarita Courthouse	1	2,629	73	161	313	34	137
	19-AK1	Norwalk Courthouse	1	8,261	377	767	3,402	194	750
	19-AO1	Whittier Courthouse	2	2,495	180	329	280	49	257
	19-AP1	Santa Monica Courthouse	1	2,879	134	231	833	37	142
	19-AQ1	Beverly Hills Courthouse	5	1,113	162	545	NS††	23	140
	19-AX2	Van Nuys Courthouse West	2	9,338	442	880	3,845	202	838
	19-G1	Burbank Courthouse	4	2,235	168	217	NS††	30	167
	19-H1	Glendale Courthouse	2	3,920	106	224	374	49	159
	19-I1	Alhambra Courthouse	1	1,021	136	361	295	77	337
	19-J1 J2	Pasadena Courthouse	5	4,755	380	534	NS††	115	454
	19-K1	Stanley Mosk Courthouse	1	25,376	676	1,396	NS††	8	32
	19-L1	Clara Shortridge Foltz Criminal Justice Center	2	8,104	797	1,853	2,338	342	1,374
	19-O1	El Monte Courthouse	4	5,571	289	440	NS††	76	281
	19-W2	Pomona Courthouse North	4	5,029	157	203	NS††	35	116
	19-X1	West Covina Courthouse	1	5,219	144	374	NS††	31	223

County	ID	Name	Selected option*	Annualized loss ($thousands)					
				Existing court building			Selected option		
				F†	RC‡	DT**	F†	RC‡	DT**
Napa	28-B1	Napa Courthouse	4	3,179	194	152	NS††	64	91
Orange	30-A1	Central Justice Center	2	17,915	694	1,935	6,780	368	1,505
	30-B1	Lamoreaux Justice Center	2	8,483	409	658	3,493	213	571
	30-C1 C2	North Justice Center	1	6,508	329	619	775	122	607
Santa Cruz	44-A1	Santa Cruz Courthouse	4	5,866	120	188	NS††	31	106

* Option 1: Baseline Retrofit
Option 2: Priority Upgrades Retrofit
Option 3: Full Renovation
Option 4: Replace to 2016 CBC
Option 5: Replace to Beyond Code

† F: annualized loss from fatalities ($thousands), which are based on peak building populations and 90th percentile estimates of fatalities from the seismic risk assessment and, thus, likely represent an upper bound on annual losses from fatalities; refer to Section V.E for findings from a sensitivity study of building populations

‡ RC: annualized loss from repair costs ($thousands)

** DT: annualized loss from downtime ($thousands); For buildings where the selected option is 1, 2, or 3, the primary intent of the retrofit is to reduce the risk of collapse and fatalities. While some reduction in downtime may be expected, the conceptual retrofit scheme does not include specific measures to reduce downtime. Therefore, downtime losses typically do not decrease significantly because of the retrofit.

†† NS: not significant. New replacement buildings (or, in the case of Stanley Mosk, base-isolated retrofits) are expected to have significantly improved seismic safety relative to current existing court buildings; therefore, in this study, fatalities were not modelled

As described in the footnotes to Table 12, annual losses from fatalities are based on peak building populations and 90th percentile estimates of fatalities from the seismic risk assessment, likely resulting in an upper bound on annual losses from fatalities. In contrast, annual losses from repair costs and downtime are based on mean estimates of repair costs and downtime, respectively, which effectively translates into a higher weighting for losses stemming from fatalities. This higher weighting is consistent with the primary focus of the study: improving the seismic safety of the current existing court building. However, it inflates the benefit-cost ratios (BCRs) presented later in this report (refer to Section V) relative to if an equivalent continuous occupancy (ECO) population were assumed for each court building. An ECO population accounts for the fact that the peak population persists for only a short period of time in a building over a typical year, so there is only a small probability that an earthquake would occur when the building is fully occupied. As a result, because the BCRs presented later in this report emphasize fatalities, they should not be considered absolute. Additional limitations in the BCR values are described in Section V.D.

Section V.E presents findings from a sensitivity study of the BCRs to the assumed building population to investigate whether the higher weighting given to fatalities might also change the relative rankings of the BCRs for each of the five retrofit or replacement options considered for each court building. In summary, changing the building population from peak to ECO, which typically reduces the number of fatalities reported by a factor of 4, does not significantly change the relative order of the retrofit and replacement options. While the BCRs were not the only factor in the decision-making process, the sensitivity study demonstrates that changes to the assumed building population do not impact the selected option for each court building.

V. COST-BENEFIT ANALYSIS

This section outlines the cost-benefit analysis performed by the consultant team to evaluate the financial effectiveness of retrofitting or replacing each of the 26 court buildings in this study. Judicial Council Facilities Services staff used results from this analysis to inform decisions about which retrofit or replacement option to pursue for each court building.

In general, cost-benefit analysis involves quantification of the benefits and costs stemming from a particular action — in this study, the retrofit or replacement of a court building. In terms of benefits, the primary consideration is the reduction in seismic risk associated with each retrofit or replacement option. Each option will improve the performance of a court building in future earthquakes to varying degree. The benefits of this improved seismic performance take the form of reduced (or avoided) fatalities, repair costs, and downtime in future earthquakes. The benefit is then compared to cost of retrofitting or replacing the building.

The cost-benefit analysis is based on standard methodologies described in FEMA P-58 (2012b), FEMA P-366 (2017), and FEMA 227 (1991), as well as other recent cost-benefit studies in the published literature (Liel and Deierlein 2013, Welch et al. 2014, Molina Hutt et al. 2015, Sullivan 2016). In overview, the analysis integrates construction cost estimates with results from the probabilistic seismic risk assessment (PSRA; refer to Section IV for additional information) to compute the benefit-cost ratio (BCR) for each retrofit and replacement option and court building. The BCR measures the value of the benefits of an option (in terms of avoided fatalities, repair costs, and downtime in future earthquakes) relative to its initial construction costs and was an important factor in deciding which retrofit or replacement option to pursue.

Section V.A describes how the costs of a retrofit or replacement option are calculated. Section V.B describes how the benefits are calculated. Section V.C describes how the BCR is calculated. Section V.D summarizes important limitations in the cost-benefit analysis. Section V.E provides sample results for the portfolio of 26 court buildings.

A. Calculation of Costs

The consultant team prepared conceptual construction cost assessments for each of the 26 existing court buildings using the proposed scopes of work for seismic upgrades, collateral impacts, fire and life safety and accessibility upgrades, priority upgrades, and other nonstructural upgrades. Where applicable, costs for hazardous materials were also identified based on input from the Judicial Council.

Costs for structural seismic work and code-required upgrades were calculated based on floor plans and narratives describing the conceptual retrofit scheme. The Judicial Council provided specific building system upgrades based on identified deferred facility modification scope items (i.e., priority upgrades). For buildings considered to be a local point of historic interest, a premium was included to cover costs for maintaining or replacing historic elements of the building. None of the buildings is on the federal or state historic buildings register, but several were identified as having features that would be considered historic.

For each court building, cost assessments are provided for the three retrofit options:

- Baseline retrofit (Option 1)
- Priority upgrades retrofit (Option 2)
- Full renovation (Option 3)

For each court building, two cost scenarios were developed for both Options 1 and 2. The first cost scenario assumes **unphased construction**, meaning that construction costs are based on the building being closed and vacated during the retrofit. In this scenario, it is assumed that new commercial building space will be fit out and rented for the duration of construction. The costs assume that an area equivalent to 75 percent of the existing space occupied by the Superior Court would need to be rented.

The second cost scenario assumes **phased construction**, meaning that additional construction costs would be incurred to keep the court building open and operational. These additional costs include premiums for phasing (assuming the work would need to be done in multiple phases either by floors or zones of the buildings), a schedule premium to cover an extended construction duration due to the phasing requirements, and an escalation premium to cover increases in the cost of labor and materials due to the extended time for construction.

Option 3 assumes only unphased construction is possible due to the increased scope of work associated with full renovation (i.e., the court building cannot be occupied during construction).

In addition, two options for replacement of the court building are assumed:

- Replace to 2016 CBC (Option 4)
- Replace to beyond code (Option 5)

For the two replacement building options, floor areas are based on the number of court departments at the existing court building and the median gross area per court department from recently constructed California court buildings. They exclude the floor area currently occupied by agencies other than the Judicial Council. In some cases, this has resulted in a bigger building being required, and in other cases a smaller one. Floor areas were provided to the consulting team by the Judicial Council.

Construction costs for replacement buildings are derived from the Judicial Council cost-model database of construction costs for California Superior Court buildings of similar scope and location constructed in the recent decade. This data was provided to the consulting team by the Judicial Council. A five percent cost premium was assumed for replacing to beyond code (Option 5) based on previous experience of the consultant team. No land costs or demolition costs are considered for the replacement buildings because these costs may not be applicable in all situations. For example, the Judicial Council could obtain land for a new facility from the city or county for free or at a significantly reduced cost. In addition, the

Judicial Council may decide to sell the current existing court building to another entity instead of demolishing it.

All construction cost estimates are provided in current dollars (2018) and market conditions, and exclude costs for future escalation because actual construction start dates have not been established at this time. Other project-related costs such as design and engineering consultant fees, loose furniture, fixtures, and equipment, and construction and owner contingencies have all been excluded. These would need to be considered and factored into overall project budgets by the Judicial Council.

B. Calculation of Benefits

Estimating the benefits of retrofitting or replacing a court building involves a significant amount of uncertainty, as the benefits can accrue over a long period of time in the future, unlike the initial construction costs, which are incurred at the beginning of a project. Furthermore, some benefits are intangible and can be challenging to quantify or measure (e.g., increased productivity or happiness of employees working in a renovated or newly-constructed building). This study focuses on the more tangible and measurable benefits of retrofitting or replacing a court building. The primary benefit is improved seismic performance, which is quantified in terms of reduced (or avoided) fatalities, repair costs, and downtime in future earthquakes. These are standard engineering risk metrics used in FEMA P-58 and previous cost-benefit studies of retrofits.

To calculate the benefits, results from the PSRA are used to compute annualized measures of performance of the existing court building and the five retrofit and replacement options. As described in Section IV, a range of seismic intensities is considered in the PSRA, from rare earthquakes to more frequent ones, which can also generate significant losses. PSRA results from each intensity are used to compute annualized losses for each retrofit and replacement option in terms of fatalities, repair costs, and downtime. Net annual benefits of an option are computed by subtracting the annualized losses for the option from the annualized losses for the current existing court building. Then, net annual benefits are summed over the assumed **asset-life extension** of the option (refer to Table 13 for additional information) and discounted to present value to obtain the net present value of benefits, $NPV_{b,i}$, as shown in Equation 4.

$$NPV_{b,i} = \Delta AAL_i \left[\frac{1 - \frac{1}{(1+r)^{T_i}}}{r} \right] \qquad \text{Equation 4}$$

Where:

$NPV_{b,i}$ = net present value of benefits for Option i, where $i = 1, \ldots, 5$

ΔAAL_i = net annual benefits of Option i

$= AAL_{existing} - AAL_{option\ i}$

$AAL_{existing}$ = annualized losses for current existing court building

$AAL_{option\ i}$ = annualized losses for Option i

T_i = assumed asset-life extension of Option i

r = discount rate, which measures the value of money in the future

The assumed asset-life extension, T_i, is an important variable in the calculation of $NPV_{b,i}$ in Equation 4, as it determines the length of time over which the benefits of retrofit or replacement can accrue. Asset-life extension is the assumed length of time — after a renovation — to the next necessary building-wide renovation or replacement. It is not a prediction of the length of court occupancy in the building (i.e., the court will not abandon or move out of the building at the end of the assumed asset-life extension). Table 13 summarizes the values of asset-life extension assumed for each option. Longer asset-life extension means that the benefits of a retrofit or replacement option have more time to accrue, thus making the option more effective from a financial perspective. The trade-off, however, is that the full renovation and replacement options, which have longer asset-life extensions than the baseline retrofit, often have significantly larger initial construction costs.

Table 13. Assumed Asset-Life Extension for Each Retrofit and Replacement Option

Option	Assumed Asset-Life Extension	Notes
1. Baseline retrofit	15 years	A relatively short asset-life extension is assumed because the baseline retrofit does not address deficient building systems, which are conservatively assumed to have 15 years remaining life. The benefits of the seismic retrofit do not cease after 15 years; however, to continue to occupy the building comfortably, additional investment would be required at that time.
2. Priority upgrades retrofit	25 years	A longer asset-life extension than the baseline retrofit is assumed because deficient building systems are replaced.
3. Full renovation	40 years	A longer asset-life extension than the priority upgrades retrofit is assumed because an entirely new building interior and facade is installed (e.g., all building systems are replaced, a more efficient and secure court layout is implemented).
4. Replace to 2016 CBC	50 years	An asset-life extension consistent with the typical design life for new building is assumed, though buildings can be occupied longer.
5. Replace to beyond code	50 years	An asset-life extension consistent with the typical design life for new building is assumed, though buildings can be occupied longer.

The discount rate, r, is another important variable in determining $NPV_{b,i}$. Because a dollar in the future is not worth the same as a dollar today, the benefits of a retrofit or replacement that accrue in the future need to be converted to present value via the discount rate. Larger discount rate values mean that money today is worth significantly more than money in the future. The federal government requires a discount rate of 7 percent for cost-benefit analysis, which is at the higher end of the range found in the published literature, reflecting the government's tendency to prioritize actions where the benefits accrue quickly (as opposed to 20 years in the future). In previous cost-benefit analyses, the consultant team used discount rates closer to 5 percent. For this study, the Judicial Council Facilities Services selected a value of 6 percent.

Annualized losses for existing court buildings, $AAL_{existing}$, and each retrofit and replacement option, $AAL_{option\ i}$, are calculated by summing the following three quantities: average annualized repair cost, average annualized downtime, and 90th percentile annualized fatalities. Figure 11 shows graphically how the average annualized repair cost is computed, for both an existing court building and the baseline retrofit. The average annualized repair cost for the existing court building is the area under the green curve, which plots the average repair cost as a function of the annual exceedance probability for the six earthquake intensities evaluated (45-year, 100-year, 225-year, 475-year, 975-year, 2,475-year). Average repair cost at each earthquake intensity is obtained from the PSRA (refer to Section IV for more information). Similarly, the average annualized repair cost for the baseline retrofit is the area under the purple curve. The difference between average annualized repair costs for the existing building and the baseline retrofit (i.e., the green shaded area in Figure 11) is the annualized benefit of the baseline retrofit (in terms of repair cost only).

The process for computing the other two annualized performance measures is the same as outlined in the previous paragraph, though for fatalities, 90th percentile values are used instead of average values. The consultant team, with input from Judicial Council Facilities Services staff, decided to use 90th percentile values because the primary goal of the study is to reduce the risk of collapse and loss of life in 26 of the most vulnerable court buildings in California. By using 90th percentile values, fatalities are given higher weighting than repair costs and downtime to emphasize the importance of this performance measure.

Before the three annualized performance measures can be summed to determine the total annualized losses (e.g., $AAL_{existing}$, $AAL_{option\ i}$), the average annualized downtime and 90th percentile annualized fatalities need to be monetized. For downtime, this involves establishing a cost associated with not being able to use a court building after an earthquake. In this study, the cost of downtime is taken as the cost to fit out and rent temporary space. Consequently, if the downtime at a court building exceeds six months after an earthquake, the court must fit out and rent temporary space while building damage is repaired. If downtime is less than six months, it is assumed that the court building can either shift cases to nearby facilities or delay them. Table 14 summarizes the costs of fitting out and renting temporary space.

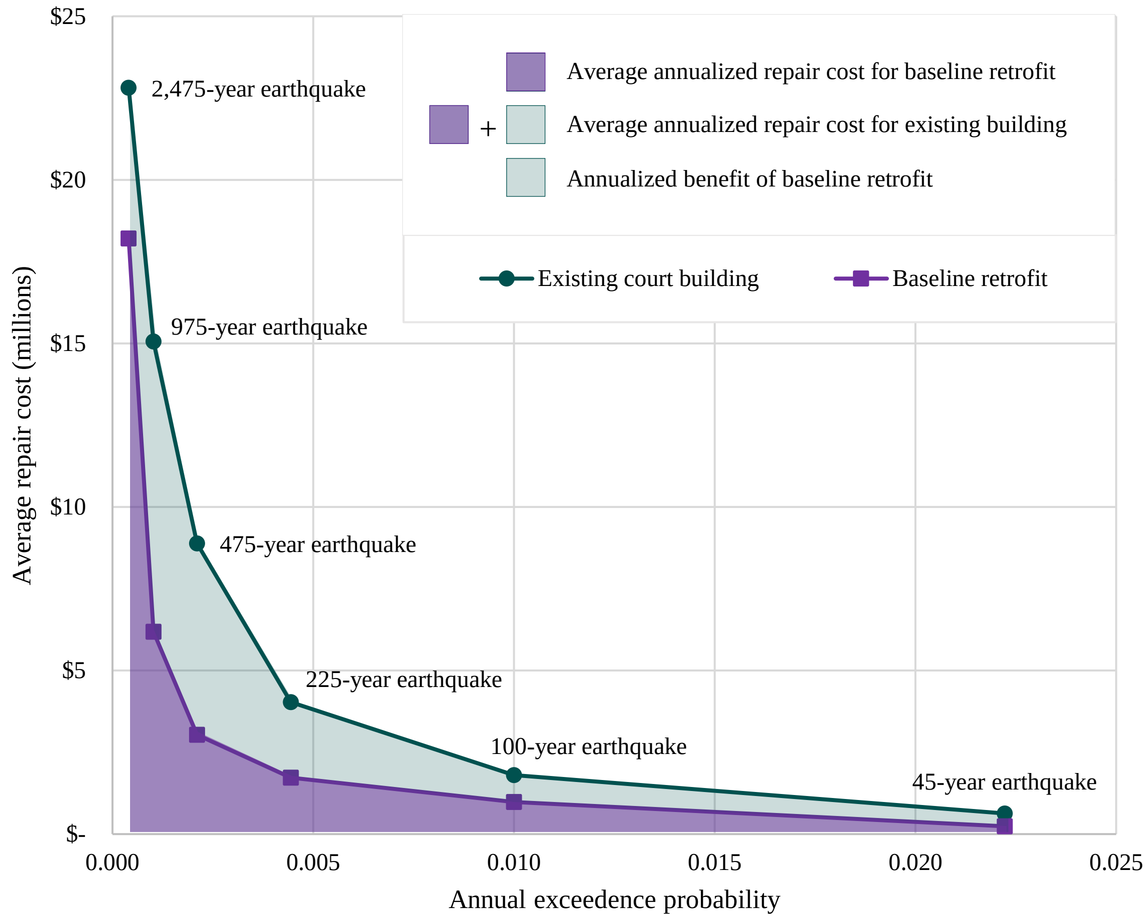

Figure 11. Plot of Average Repair Cost as a Function of the Annual Exceedance Probability for the Six Earthquake Intensities Evaluated

Table 14. Summary of Costs Associated with Fitting Out and Renting Temporary Space

Location	Area rented	Fit out costs	Rental costs (per year)
Urban	75% of current existing court building	\$250 per ft^2	\$50 per ft^2
Rural	75% of current existing court building	\$250 per ft^2	\$30 per ft^2

To monetize the cost of fatalities, the value of a statistical life needs to be established. The consultant team reviewed previous cost-benefit studies to determine an appropriate value for this study. Numerous federal agencies, including the Environmental Protection Agency, Department of Agriculture, and Food and Drug Administration, use values between $8 and $10 million (in 2018 dollars). In contrast, academic studies tend to use lower values, typically between $2 and $5 million. In consultation with Judicial Council Facilities Services staff, a value of $9 million was selected for this study.

C. Calculation of Benefit-Cost Ratio

The financial effectiveness of each retrofit and replacement option is evaluated by computing the benefit-cost ratio (BCR) per Equation 5. The BCR measures the value of the benefits of an option (in terms of avoided fatalities, repair costs, and downtime in future earthquakes) relative to its initial construction costs. Values greater than one indicate that the benefits of an option, over the assumed asset-life extension, exceed the initial construction costs. Based on prior experience of the consultant team, it is not uncommon that BCRs for all options remain below one; however, even in this situation, the BCRs are still useful in terms of prioritizing which option makes the most sense to pursue.

$$BCR_i = \frac{NPV_{b,i}}{NPV_{c,i}} \qquad \text{Equation 5}$$

Where:

BCR_i = benefit-cost ratio of Option i

$NPV_{b,i}$ = net present value of benefits for Option i (see Equation 4)

$NPV_{c,i}$ = net present value of costs for Option i
= total initial construction costs for Option i

The BCR is an important consideration in the decision-making process because it incorporates a wide range of factors into a single measure, including the reduction in seismic risks (e.g., fatalities, repair costs, downtime), asset-life extension, and total construction costs. If the retrofit or replacement option with the highest BCR had a value that was significantly larger than the option with the next highest BCR value (the consultant team established 25 percent as the threshold for significantly larger), then it was selected as the option to pursue. The 25 percent threshold was established because the uncertainty in calculating the BCR was such that two values within ± 25 percent of each other could be considered similar.

If the BCRs for each option were similar, then additional metrics were considered in the selection process, including total construction costs, cost per square foot, and the ratio of total construction costs to asset-life extension.

Table 15 compares benefit-cost ratios (BCRs) of the selected retrofit or replacement options across the portfolio of 26 court buildings included in this study. Court buildings are sorted from highest BCR to lowest. Court buildings with the largest BCRs represent the best retrofit or replacement investments, but additional factors (e.g., total construction cost, importance of the existing court building to continuing Superior Court operations) need to be considered in developing judicial branch-wide renovation strategies or priorities. The total construction cost associated with retrofitting or replacing all 26 court buildings is $2.3 billion.

Table 15. Comparison of Construction Costs and Benefit-Cost Ratios for 26 Court Buildings

County	ID	Name	Court departments	Selected option*	Total construction cost (millions)	Benefit-cost ratio	Asset-life extension (years)
Imperial	13-A1	Imperial County Courthouse	7	4	$48.9	6.78	50
Lake	17-B1	Clearlake Branch Courthouse	1	4	$8.0	2.50	50
Los Angeles	19-O1	El Monte Courthouse	6	4	$41.0	2.28	50
Los Angeles	19-X1	West Covina Courthouse	11	1	$23.6	2.26	15
Contra Costa	07-F1	George D. Carroll Courthouse	8	4	$82.2	1.98	50
Los Angeles	19-AD1	Santa Clarita Courthouse	3	1	$12.1	1.92	15
Santa Cruz	44-A1	Santa Cruz Courthouse	7	4	$49.8	1.91	50
Los Angeles	19-W2	Pomona Courthouse North	7	4	$47.9	1.72	50
Napa	28-B1	Napa Courthouse	4	4	$32.6	1.63	50
Alameda	01-F1	George E. McDonald Hall of Justice	3	2	$18.4	1.61	25
Los Angeles	19-AK1	Norwalk Courthouse	20	1	$45.9	1.07	15
Los Angeles	19-H1	Glendale Courthouse	8	2	$44.0	1.07	25
Orange	30-A1	Central Justice Center	65	2	$196.5	0.77	25
Orange	30-C1 C2	North Justice Center	18	1	$75.4	0.77	15
Los Angeles	19-G1	Burbank Courthouse	7	4	$50.4	0.76	50
Fresno	10-A1	Fresno County Courthouse	28	1	$103.0	0.65	15
Orange	30-B1	Lamoreaux Justice Center	29	2	$106.7	0.63	25
Los Angeles	19-K1	Stanley Mosk Courthouse	100	1	$461.3	0.58	15
Los Angeles	19-AO1	Whittier Courthouse	7	2	$54.3	0.57	25
Los Angeles	19-AQ1	Beverly Hills Courthouse	6	5	$47.3	0.55	50

County	ID	Name	Court departments	Selected option*	Total construction cost (millions)	Benefit-cost ratio	Asset-life extension (years)
Los Angeles	19-J1 J2	Pasadena Courthouse	19	5	$165.3	0.52	50
Contra Costa	07-A2	Wakefield Taylor Courthouse	12	2	$64.6	0.47	25
Los Angeles	19-AX2	Van Nuys Courthouse West	23	2	$160.4	0.46	25
Los Angeles	19-AP1	Santa Monica Courthouse	17	1	$50.5	0.43	15
Los Angeles	19-L1	Clara Shortridge Foltz Criminal Justice Center	60	2	$300.2	0.26	25
Los Angeles	19-I1	Alhambra Courthouse	9	1	$42.3	0.19	15

* Option 1: Baseline Retrofit
Option 2: Priority Upgrades Retrofit
Option 3: Full Renovation
Option 4: Replace to 2016 CBC
Option 5: Replace to Beyond Code

As described in the footnotes to Table 12, annual losses from fatalities are based on peak building populations and 90th percentile estimates of fatalities from the seismic risk assessment, likely resulting in an upper bound on annual losses from fatalities. In contrast, annual losses from repair costs and downtime are based on mean estimates of repair costs and downtime, respectively, which effectively translates into a higher weighting for losses stemming from fatalities. This higher weighting is consistent with the primary focus of the study: improving the seismic safety of the current existing court building. However, it inflates the BCRs presented later in Table 15 relative to if an equivalent continuous occupancy (ECO) population were assumed for each court building. An ECO population accounts for the fact that the peak population persists for only a short period of time in a building over a typical year, so there is only a small probability that an earthquake would occur when the building is fully occupied. As a result, because the BCRs presented in Table 15 emphasize fatalities, they should not be considered absolute. Additional limitations in the BCR values are described in Section V.D.

Section V.E presents findings from a sensitivity study of the BCRs to the assumed building population to investigate whether the higher weighting given to fatalities might also change the relative rankings of the BCRs for each of the five retrofit or replacement options considered for each court building. In summary, changing the building population from peak to ECO, which typically reduces the number of fatalities reported by a factor of 4, does not change the relative order of the retrofit and replacement options. While the BCRs were not the only factor in the decision-making process, the sensitivity study demonstrates that changes to the assumed building population do not impact the selected option for each court building.

D. Limitations

The cost-benefit analysis considers a limited set of costs and benefits, as summarized in Table 16.

On the cost side, only hard construction costs and phasing or relocation costs are considered for each retrofit and replacement option. Costs for future escalation, design and engineering consultant fees, loose furniture, fixtures, and equipment, and construction and owner contingencies are not included. For the replacement options, land costs and demolition costs are not included. Refer to Section V.A for additional discussion. In general, inclusion of these costs would make each option more expensive, which, per Equation 5, would reduce its corresponding BCR. While the BCRs of all retrofit and replacement options would decrease, the relative change among the options for an individual court building is more difficult to predict.

Table 16. Summary of Costs and Benefits Included in Cost-Benefit Analysis

Item	Included in cost-benefit analysis					Notes
	Retrofit or replacement option					
	1	2	3	4	5	
Costs						
Hard construction costs	Yes	Yes	Yes	Yes	Yes	Includes costs of site preparation, design contingencies, and labor and material required for repair or construction of substructure, shell, interiors, and building services (as applicable). For Options 1 and 2, the costs of upgrades to accessibility and fire and life safety systems were explicitly calculated. For Options 3-5, compliance with current accessibility and fire and life safety requirements is assumed as part of the construction work.
Temporary relocation costs	Yes	Yes	Yes	N/A	N/A	For Options 1-3 (unphased), includes fit out and rental costs required to relocate court staff and functions to temporary space for the duration of the retrofit. For Options 4-5, temporary relocation costs are not applicable because it is assumed court staff and functions can remain in the existing court building while the new one is constructed in a nearby location.
Construction phasing costs	Yes	Yes	No	N/A	N/A	For Options 1 and 2 (phased), includes costs for phasing the construction work by zones or floors to keep the court building open during the retrofit. For Option 3, construction phasing costs were not included because phasing was assumed to be impractical due to disruptiveness of the construction work.

Item	Included in cost-benefit analysis					Notes
	Retrofit or replacement option					
	1	2	3	4	5	
Demolition costs	N/A	N/A	N/A	No	No	For Options 4 and 5, does not include costs of demolishing current existing building. For Options 1-3, demolition costs are not applicable.
Land costs	N/A	N/A	N/A	No	No	For Options 4 and 5, does not include costs of acquiring land for new court building. For Options 1-3, demolition costs are not applicable.
Escalation costs	No	No	No	No	No	Does not include escalation in construction costs from the time of this study to the actual start of a retrofit or replacement project.
Design and engineering consultant fees	No	No	No	No	No	Does not include consultant fees for further engineering analyses or detailed design services prior to retrofit or replacement of a court building.
Construction and owner contingencies	No	No	No	No	No	
Loose furniture, fixtures, and equipment	No	No	No	No	No	
Benefits						
Avoided injuries in future earthquakes	No	No	No	No	No	Does not include the benefit of avoided injuries due to incomplete data on the financial cost of injuries.
Avoided fatalities in future earthquakes	Yes	Yes	Yes	Yes	Yes	Includes the benefit of avoided fatalities. Fatalities were calculated using peak instantaneous building populations, which were derived from magnetometer counts for each court building, and 90th percentile estimates of fatalities from the seismic risk assessment. The value of a statistical life (i.e., cost of a fatality) was selected to be $9 million for this study. Refer to Section V.B for further discussion.
Avoided repair costs in future earthquakes	Yes	Yes	Yes	Yes	Yes	Includes costs to repair damage to major structural and nonstructural components. Does not include losses from damage to building contents (e.g., furniture, computers).
Avoided downtime in future earthquakes	Yes	Yes	Yes	Yes	Yes	Includes cost to fit out and rent temporary space for the duration of repair work after an earthquake. Does not include indirect costs from protracted downtime (e.g., increased backlog of court cases, employee attrition)

Item	Included in cost-benefit analysis					Notes
	Retrofit or replacement option					
	1	2	3	4	5	
Improved energy efficiency	No	No	No	No	No	Does not include the benefit of improved energy efficiency from replacing existing mechanical and electrical equipment.
Improved accessibility	No	No	No	No	No	
Improved fire and life safety	No	No	No	No	No	
Improved functionality	No	No	No	No	No	Does not include the benefit of improved functionality from construction work, including possible improvements to daylighting, security, and building layout.
Asset-life extension						
Minimum asset-life extension (years)	15	25	40	50	50	Asset-life extension refers to the assumed life time of a building before further necessary building-wide renovation or replacement is required. It is the length of time over which the benefits (above) are assumed to accrue. It is not a prediction of the length of actual court occupancy in a particular building. Refer to Section V.B for further discussion.

On the benefit side, only repair costs, fatalities, and downtime stemming from structural and nonstructural damage are considered when determining the benefits of each retrofit and replacement option. Losses from damage to building contents are not included; neither are indirect costs stemming from protracted downtime (e.g., increased backlog of court cases, employee attrition). In addition, energy savings from a new facade or HVAC equipment are not included. These benefits, some of which are difficult to quantify, would generally increase the BCRs, making each option more attractive. While the BCRs of all options would increase, the relative change among the options for an individual court building is more difficult to predict.

E. Sensitivity Studies

Many of the inputs to the cost-benefit analysis carry significant uncertainty that stems from various sources, including incomplete knowledge (e.g., compressive strength of existing concrete) and use of simplistic calculation methods (e.g., simplified structural analysis procedures to compute EDPs; see Section IV.C). As described in Section IV.A, the PSRA, which provides important inputs to the cost-benefit analysis, explicitly accounts for uncertainty through Monte Carlo analysis, a process in which hundreds to thousands of simulations are performed to determine the range of possible outcomes after an earthquake scenario.

Subsequently, the cost-benefit analysis accounts for uncertainty indirectly via the inputs it obtains from the PSRA, including estimates of fatalities, repair costs, and downtime. While sensitivity studies were not performed for each major input to the cost-benefit analysis, the consultant team explored the impact of a particularly important parameter — building population — on the relative order of BCRs for each court building. Towards this end, the consultant team reran both the PSRA and cost-benefit analysis using ECO rather than peak building populations to study whether the relative order of the BCRs for the five retrofit and replacement options changed for any of the 26 court buildings.

As discussed in Section V.C, using peak building populations inflates the BCRs for all options, meaning the values presented in Table 15 should not be considered absolute. More important, however, is the relative order of the BCRs for each retrofit and replacement option, as that is what informed the final decision-making process for each court building (though other factors were considered). Therefore, the sensitivity study investigates whether using ECO populations, which more accurately reflect the building population over the course of a typical year, would significantly change the relative order of the BCRs.

Table 17 summarizes findings from the sensitivity study. It shows the changes, if any, to the options with the highest BCR using peak and ECO populations. For most court buildings, the option with the highest BCR does not change after adjusting the building population. For five court buildings, however, the option does change. For these buildings, the closeness parameter reported in the last column of Table 17 measures the percent difference between the option with the highest BCR using peak populations and the option with the highest BCR using ECO populations. Values within 25% are considered to be similar due to the significant uncertainties associated with calculating the BCRs.

For example, for the North Justice Center, the option with the highest BCR using peak populations is Option 1, while the option with the highest BCR using ECO populations is Option 4/5 (for the purposes of the sensitivity study, the two replacement options were considered interchangeable). While the option with the highest BCR changed, the BCR for Option 1 using ECO populations is within 14% of Option 4/5, which has the highest BCR. Consequently, the resulting change is not considered significant because both BCRs are with 25 percent.

As Table 17 shows, even for court buildings where the option with the highest BCR changes, the two options are still within 25 percent of each other. Consequently, changing the building populations does not significantly alter the relative ranking of the BCRs for each court building. While the BCRs were not the only factor in the decision-making process, the sensitivity study demonstrates that changes to the assumed building population do not impact the selected option for each court building.

Table 17. Summary of Findings from Sensitivity Study of Building Populations

ID	Name	Option w highest BCR (peak populations)*	Option w highest BCR (ECO populations)*	Closeness†
01-F1	George E. McDonald Hall of Justice	2	2	match
07-A2	Wakefield Taylor Courthouse	4/5	4/5	match
07-F1	George D. Carroll Courthouse	4/5	4/5	match
10-A1	Fresno County Courthouse	3	4/5	1%
13-A1	Imperial County Courthouse	4/5	4/5	match
17-B1	Clearlake Branch Courthouse	4/5	4/5	match
19-AD1	Santa Clarita Courthouse	1	4/5	4%
19-AK1	Norwalk Courthouse	1	1	match
19-AO1	Whittier Courthouse	4/5	4/5	match
19-AP1	Santa Monica Courthouse	1	1	match
19-AQ1	Beverly Hills Courthouse	4/5	4/5	match
19-AX2	Van Nuys Courthouse West	4/5	4/5	match
19-G1	Burbank Courthouse	4/5	4/5	match
19-H1	Glendale Courthouse	2	2	match
19-I1	Alhambra Courthouse	4/5	4/5	match
19-J1 J2	Pasadena Courthouse	4/5	4/5	match
19-K1	Stanley Mosk Courthouse	1	1	match
19-L1	Clara Shortridge Foltz Criminal Justice Center	4/5	4/5	match
19-O1	El Monte Courthouse	4/5	4/5	match
19-W2	Pomona Courthouse North	1	4/5	3%
19-X1	West Covina Courthouse	1	1	match
28-B1	Napa Courthouse	4/5	4/5	match
30-A1	Central Justice Center	2	2	match
30-B1	Lamoreaux Justice Center	2	4/5	6%
30-C1 C2	North Justice Center	1	4/5	14%
44-A1	Santa Cruz Courthouse	3	3	match

* Option 1: Baseline Retrofit
Option 2: Priority Upgrades Retrofit
Option 3: Full Renovation
Option 4/5: Replacement (for the purposes of the sensitivity study, the two replacement options were considered interchangeable)

† Closeness measures the percent difference between the option with the highest BCR using peak populations and the option with the highest BCR using ECO populations, with values within 25% considered to be similar due to uncertainty in calculating the BCRs. For example, for the North Justice Center, the option with the highest BCR using peak populations is Option 1, while the option with the highest BCR using ECO populations is Option 4/5. However, the BCR

for Option 1 using ECO populations is within 14% of Option 4/5, which has the highest BCR. Consequently, the closeness is reported as 14%.

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APPENDIX A. ABBREVIATIONS AND GLOSSARY

A. Abbreviations

ASCE	American Society of Civil Engineers
BCR	benefit-cost ratio
BPOE	basic performance objective for existing buildings
CBC	California Building Code
CBSC	California Building Standards Commission
CEBC	California Existing Building Code
EDP	engineering demand parameters
FEMA	Federal Emergency Management Agency
IDR	interstory drift ratio
PSRA	probabilistic seismic risk assessment
R+C	Rutherford + Chekene
REDi	Resilience-based Earthquake Design Initiative
SRR	seismic risk rating
UHS	uniform hazard spectrum
USGS	United States Geological Survey

B. Glossary

Asset-life extension – For a given retrofit or replacement option, the assumed life time of a building before further necessary building-wide renovation or replacement renovation is required. This is used to calculate total benefit. Asset-life extension is not a prediction of the length of actual court occupancy in a particular building.

Authority having jurisdiction – An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure (NFPA 2014).

Baseline retrofit option (Option 1) – A retrofit option that represents the minimum level of effort and expenditure to mitigate the seismic risk at a court building, including seismic upgrades to structural and nonstructural components (e.g., stairs, elevators, ceilings, lights, partitions) to achieve Risk Level IV performance (i.e., ASCE 41-13 BPOE for Risk Category II structures), nonstructural repairs made necessary by the retrofit, and triggered upgrades to accessibility and fire and life safety systems.

BSE-1E – Basic safety earthquake-1 for use with the BPOE, taken as a seismic hazard with a 20% probability of exceedance in 50 years, but not greater than the BSE-1N, at a site.

BSE-1N – Basic safety earthquake-1 for use with the basic performance objective equivalent to new building standards (BPON), taken as two-thirds of the BSE-2N at a site.

BSE-2E – Basic safety earthquake-2 for use with the BPOE, taken as a seismic hazard with a 5% probability of exceedance in 50 years, but not greater than the BSE-2N, at a site.

BSE-2N – Basic safety earthquake-2 for use with the BPON, taken as the ground shaking based on the Risk-Targeted Maximum Considered Earthquake (MCE_R) per ASCE 7-10 at a site.

Building segment – A portion of a building that may respond independently of other sections in an earthquake. Building segments can have very different properties (e.g., construction material and number of floors), and can be built at different times. However, from an operational perspective, they typically function together as a single facility.

Building type – A classification that groups buildings with common seismic-force-resisting systems and performance characteristics in past earthquakes. The building types relevant to the 26 court buildings in this study include those listed in the table below (ASCE 2003):

Type	Description
C1	Concrete moment frames
C2	Concrete shear walls with stiff diaphragms
C2A	Concrete shear walls with flexible diaphragms
PC1A	Precast/tilt-up concrete shear walls with stiff diaphragms
RM1	Reinforced masonry bearing walls with flexible diaphragms
RM2	Reinforced masonry bearing walls with stiff diaphragms
S1	Steel moment frames with stiff diaphragms
S2	Steel braced frames with stiff diaphragms
S4	Steel frames with concrete shear walls
URM	Unreinforced masonry bearing walls with flexible diaphragms

California Building Code (CBC) – The set of regulations in California that governs how new buildings are designed and constructed.

California Existing Building Code (CEBC) – The set of regulations in California that governs how existing buildings are repaired, altered, or expanded.

Collapse prevention performance – A post-earthquake damage state in which a building is on the verge of partial or total collapse. Substantial damage to the structure has occurred, potentially including significant degradation in the stiffness and strength of the lateral-force-resisting system, large permanent lateral deformation of the structure, and—to a more limited extent—degradation in vertical-load-carrying capacity. However, all significant components of the gravity-load-resisting system must continue to carry their gravity loads. Significant risk of injury caused by falling hazards from structural debris might exist. The structure might not be technically practical to repair and is not safe for re-occupancy because aftershock activity could induce collapse.

Collapse probability – The likelihood that a building will either partially or totally collapse in an earthquake. FEMA P-154 (2015) defines *collapse* as when the gravity load carrying system in part or all of the building loses the ability to carry the weight.

Collateral impacts – Repair work to nonstructural components (e.g., walls, ceilings, lighting, carpeting) made necessary by the seismic retrofit.

Design basis earthquake – A level of ground shaking defined in the design standards for new buildings (e.g., ASCE 7). For California, this has a return period of between 200 and 800 years.

FEMA P-58 risk assessments – A standard engineering method for quantifying the seismic performance of a building in terms of casualties, repair costs, and repair time.

Full renovation option (Option 3) – A retrofit option that includes the same seismic upgrades to structural components as the baseline retrofit option, plus full demolition and replacement of the interior down to the structural skeleton and removal of the exterior wall and roof cladding. The budget for the nonstructural components is based unit costs per square foot, and no design was performed as part of this study.

Life safety performance – A post-earthquake damage state in which significant damage to a building has occurred but some margin against either partial or total structural collapse remains. Some structural components are severely damaged, but this damage has not resulted in large falling debris hazards, either inside or outside the building. Injuries might occur during the earthquake; however, the overall risk of life-threatening injury from structural damage is expected to be low. It should be possible to repair the structure; however, for economic reasons, this repair might not be practical. Although the damaged structure is not an imminent collapse risk, it would be prudent to implement structural repairs or install temporary bracing before re-occupancy.

Nonstructural components – Architectural, mechanical, and electrical components of a building permanently installed in or integral to a building system.

Phased construction – A scenario in which the court building would be kept open and operational during the retrofit, requiring the work would need to be done in multiple phases either by floors or zones of the buildings.

Priority upgrades – A list of approved, unfunded facility modifications at a court building. Priority upgrades do not include all possible maintenance needs at a court building.

Priority upgrades retrofit option (Option 2) – A retrofit option that includes the same upgrades as the baseline retrofit option, plus any priority upgrades. This retrofit option was included in the study because seismic retrofits often provide an opportunity to upgrade outdated or deficient building systems (which would normally be highly disruptive) at relatively little additional cost

Replace to 2016 CBC option (Option 4) – A replacement option that involves replacing an existing court building with a new facility that satisfies Risk Category III requirements of the 2016 California Building Code (CBC). Risk Category III refers to "buildings and structures that could pose a substantial risk to human life in case of damage or failure," including those with a potential to cause "a substantial economic impact and/or mass disruption of day-to-day civilian life" (ASCE 2013). California Superior Court buildings are classified as Risk Category III because of the consistent large density of occupants in these public buildings.

Replace to beyond code option (Option 5) – A replacement option that involves replacing an existing court building with a new facility that goes beyond the minimum requirements of the 2016 CBC to achieve more resilient seismic performance (e.g., reduced damage, repair costs, and downtime).

Seismic risk rating (SRR) – A ranking based on the relative probability of collapse in a seismic event as estimated by a Hazus model of the building, which considers the structural capacity of the building, site-specific seismic hazard, and structural characteristics that influence the capacity or response to earthquakes. Court buildings with SRRs exceeding 10 are classified as Very High Risk, while those with SRRs between 2 and 10 are classified as High Risk.

Structural components – Components of a building that provide gravity- or lateral-load resistance as part of a continuous load path to the foundation, including beams, columns, slabs, braces, walls, wall piers, coupling beams, and connections.

Supplemental ASCE 41-13 Tier 1 seismic assessment – A standard ASCE 41-13 Tier 1 seismic evaluation involves completing checklists of evaluation statements to identify seismic deficiencies in a building based on performance of similar buildings in past earthquakes. It does not require checking the adequacy of supporting elements in the load path once the deficient components have been retrofitted, or checking the performance of the entire seismic-force-resisting system. Both checks were included in the supplemental seismic evaluations performed by the consultant team.

Unphased construction – A scenario in which the court building is closed and vacated during construction, requiring court staff and functions to be relocated to a temporary facility.

APPENDIX B. R+C PEER REVIEW LETTER

Appendix B provides a letter from Rutherford + Chekene, structural peer reviewer to the Judicial Council, stating their professional opinion about overall appropriateness or validity of the methodology used for the seismic renovation feasibility study.

7 January 2019

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2018-032S, Task 1

Subject: **CALIFORNIA SUPERIOR COURT BUILDINGS SEISMIC RENOVATION FEASIBILITY STUDIES**
SEISMIC PEER REVIEW FINDINGS

Dear Mr. Ham:

On behalf of the Judicial Council of California, Rutherford and Chekene performed Seismic Peer Review for the Court Renovation Feasibility Studies project. The purpose of this project was to create individual Project Feasibility Reports defining the feasibility, scope and budget for renovation construction to mitigate the seismic safety risks in 26 existing superior court facilities with very high or high seismic risk ratings.

Each study involved developing a conceptual seismic retrofit scheme, determining the collateral impacts and associated construction costs of the retrofit scheme and renovation options, and performing cost-benefit analyses to determine the most appropriate renovation strategy for the subject facility. A total of five retrofit and replacement options were considered for each facility. In addition to a seismic retrofit only project (option 1), additional options were developed that included seismic retrofit with priority building infrastructure and systems upgrades (option 2), seismic retrofit with full building renovation (option 3), building replacement (option 4), and building replacement with enhanced performance (option 5). The consultant team then performed costs-benefit analyses to compare the financial effectiveness of the five retrofit and replacement options for each facility. The benefit-cost ratio was the primary consideration of the Judicial Council Facilities Services staff's decision of which retrofit or replacement option to select.

The goal of the peer review was to advice the Judicial Council Facilities Services on the validity of structural engineering performance criteria for the strategic approaches to building renovation, e.g. Life-Safety, Current Code, Enhanced Performance, and the validity of the structural engineering design concepts proposed by Consultant for the building renovations.

This letter summarizes our findings related to the methodology used to develop the retrofit concepts and calculate Benefit-Cost Ratios for the various options considered for each facility, and our findings regarding the validity of the engineering design concept for the building renovation/ retrofit to meet the intended seismic performance level.

FINDINGS

1. The project used the ASCE 41-13 Basic Performance Objective for Existing Buildings for Risk Category II buildings as the Structural Design Criteria for evaluation and retrofit design.

This seismic performance objective is considered equivalent to (and therefore achieves) Risk Level IV performance, which is the minimum performance level required by the Judicial Council of California for the seismic retrofit of court buildings and meets the minimum requirements of the 2016 California Existing Building Code (CEBC) for State Owned Buildings, as stated in Table 317.5 of CEBC - California Code of Regulations – Title 24, Part 10.

2. The consultant team used the ASCE 41-13 Tier 1 Screening procedure and the most recent seismic hazard information for California, supplemented with numerical checks of the adequacy of the load path and seismic force-resisting system to evaluate each building. Based on the deficiencies identified by this seismic evaluation, the consultant team developed a conceptual retrofit scheme to mitigate each deficiency.

3. The scope of architectural impacts and triggered improvements is extensive, and constitutes a significant portion of the retrofit costs.

4. The seismic retrofit drawings incorporate standard structural details, typically taken from the FEMA document "*Techniques for the Seismic Rehabilitation of Existing Buildings*", FEMA 547. Though these details may not reflect the actual construction of the court building and are not developed in enough detail for the purpose of construction, they are typically adequate to convey the intent of the retrofit to the cost estimator.

5. Some of the facilities such as the Central Justice Center (30-A1), the Glendale Courthouse (19-H1), the Imperial County Courthouse (13-A1), the Napa Courthouse (28-B1), and the Wakefield Taylor Courthouse (07-A2) are local points of historic interest, or have historically significant architectural features. Though some attention was given to avoid modification of exterior appearance, interior public space and courtrooms when developing the retrofit concept, it may be expected that the final retrofit design would focus on localizing the retrofit work to the extent possible and would consider additional retrofit schemes to further reduce the impact of the retrofit construction on the historically significant elements.

6. The calculation of seismic benefit-cost ratios is primarily based on the method published in the FEMA document "*Seismic Performance Assessment of Buildings*", FEMA P-58. The method is comprehensive and relatively complex and requires development of many input parameters. The scope of the feasibility studies was limited, requiring determination of many of the parameters more efficiently than recommended by the P-58 methodology, often essentially by engineering judgment. As pointed out in the Detailed Methodology Report, many of the input parameters and resulting output have large uncertainties. Uncertainty is always present in seismic analysis and related calculations, largely due to the uncertainty in the ground motion itself. The methodology used in these reports takes uncertainty into account explicitly, enabling the user to study the potential effects of various uncertainties. Since the methods used for each building and each alternative (and related uncertainties) are consistent throughout the study, the relative values of the results should be sufficiently stable to be used for comparison of various actions.

7. Losses due to casualties are monetized using values common in the industry. However, the number of casualties estimated by the study is exceptionally high. This is due to use of a large occupancy (number of people in the building exposed to damage or collapse), derived from JCC counts of entries into each building. This method, in itself, is susceptible to double counting, but also many studies of the kind use the Equivalent Continuous Occupancy (ECO) which averages occupancy over 24 hour days and 7 day weeks. The ECO is

typically one third of the normal daytime occupancy. In addition, the casualties used to estimate benefit and costs was taken as the 90th percentile of the probabilistic calculation rather than the mean taken for other loss parameters. Studies documented in the Detailed Methodology Report indicate that the assumptions resulting in high casualties and monetized losses have little effect on relative values between options and between buildings and therefore do not invalidate the results of the study.

8. When considering a replacement building as an option, the size and construction cost of each replacement building was provided by the Judicial Council; the gross area is an estimate, subject to change with detailed design, but suitable for these reports. The configuration and structural system of the new building and its site on the other hand were unknown, and detailed loss models could not be developed as a result. Therefore, loss values for the replacement buildings were proportioned using linear scaling factors from losses calculated for the existing building. Although losses from a new building would normally be less than from an existing retrofitted building, it is unclear if all losses have the same proportionality or how variations in the reduced losses could affect the benefits of these options.

9. The benefit-cost ratios calculated in this study are relatively low, often below 1.0. One reason for this result is that there are high costs related to the non-seismic upgrades (e.g. sprinklers, disabled access, mechanical, etc.) required for most of these buildings. The total costs of installation of these systems are included in the "costs" but there are only small seismic-related "benefits;" and therefore the *seismic* cost-benefit ratios are lowered.

To an extent consistent with the scope of our review, our professional opinion is that the retrofit concept presented in this report when further developed into construction documents will be capable of achieving a Risk Level IV and minimum code requirements and is adequate for the purpose of developing conceptual cost estimates used for budget purposes.

We further find that the methodology and assumptions used to calculate cost-benefit ratios for the 5 retrofit and replacement option considered are reasonable and the results properly considered for the purposes of these studies.

SCOPE OF SERVICES

We carried out the Seismic Peer Review in accordance with the agreed upon scope of work, included in our Work Order No. 1035898 with the Judicial Council of California. The scope of our review is summarized below:

- Participated in regular meetings and conference calls between April and November 2018.
- Participated in a series of workshops where design assumptions, retrofit design concepts and benefit-cost ratios were presented and discussed.
- Reviewed submitted information and reports for each building, provided comments, and worked with the consultant team to reach resolution of comments.
- Issued a letter for each building stating our professional opinion about performance criteria for strategic approaches to building renovation/conceptual retrofit design.
- Provided a letter stating our professional opinion about overall appropriateness of the processes used for this project relative to current best engineering practices.

Rutherford + Chekene staff participating in the review were Ayse Celikbas, William Holmes, Afshar Jalalian, and Marko Schotanus.

Please contact us at (415) 568-4400 if you wish to discuss any elements of the review.

Sincerely,

RUTHERFORD + CHEKENE

Afshar Jalalian, S.E.
Executive Principal

cc: Michael Mieler, Rob Smith, Ibrahim Almufti – Arup, San Francisco