PRIORITIZING SEISMIC INVESTMENTS: PORTFOLIO RISK ASSESSMENT USING ASCE 41 AND SP3

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Abstract

In 2024, a City in Northern California initiated a seismic risk assessment of more than 90,000 square feet of municipal facilities to support capital planning and emergency preparedness. The portfolio included fire stations, a police station, City Hall, and other essential and non-essential facilities. The objective was to evaluate expected seismic performance and quantify potential losses to inform decisions regarding retrofit, replacement, continued use, further investment, sale, or decommissioning.

The project combined ASCE/SEI 41 Tier 1 and selected Tier 2 evaluations of fifteen existing buildings with probabilistic loss assessments performed using the Seismic Performance Prediction Program (SP3). While ASCE 41 identifies structural deficiencies relative to prescribed performance objectives, SP3 estimates the consequences of those deficiencies in terms of repair cost, functional recovery, casualty risk, and annualized loss.

This paper presents a practical workflow for integrating ASCE 41 evaluations with SP3 portfolio-level risk modeling and demonstrates its application through representative case studies. The resulting methodology provides owners with technically defensible and financially meaningful metrics that support prioritization of seismic mitigation and other investment and capital decisions across existing building portfolios.

1.0 Introduction

1.1 The Owner Decision Problem

Owners of existing buildings in seismic regions are increasingly required to make risk-informed decisions regarding seismic mitigation. Municipal agencies, universities, healthcare systems, and private organizations often manage portfolios consisting of dozens or hundreds of buildings with varying structural systems, occupancies, and replacement values. Limited capital budgets require these owners to prioritize retrofit investments based not only on engineering considerations but also on expected financial and operational consequences.

Traditional seismic evaluations provide only part of the information required for these decisions. ASCE/SEI 41 establishes nationally recognized procedures for evaluating existing buildings and identifying structural deficiencies relative to defined performance objectives. These procedures are well suited for demonstrating regulatory compliance and identifying retrofit needs. However, they do not directly answer the questions that often govern capital planning:

- Which buildings represent the greatest financial risk?
- Which buildings represent the most impactful life safety or operational risk?
- What are the expected consequences of deferring retrofit?
- Which retrofit projects provide the greatest reduction in future loss?

Answering these questions requires translating structural performance into consequences that owners can compare across an entire building portfolio. While structural deficiencies provide the engineering basis for retrofit, they do not indicate which deficiencies present the greatest financial or operational risk, which retrofit strategies provide the greatest return

on investment, or how competing capital projects should be prioritized. As a result, engineers are increasingly being asked to supplement traditional structural evaluations with information that better supports owner decision-making.

1.2 Existing Evaluation and Risk Assessment Tools

ASCE/SEI 41 provides a systematic framework for evaluating existing buildings through Tier 1 screening, Tier 2 deficiency-based evaluations, and Tier 3 nonlinear analyses. The output is fundamentally engineering-based: individual structural components are evaluated against prescribed acceptance criteria, resulting in identification of deficiencies that must be addressed to achieve the selected performance objective.

Probabilistic loss assessment complements this approach by estimating the consequences of earthquake damage in terms meaningful to owners, including repair cost, functional recovery, and life-safety or operational risk. Recent tools, such as the Seismic Performance Prediction Program (SP3), have made these assessments practical for portfolio-level applications by substantially reducing the analytical effort required.

Together, these methodologies provide complementary perspectives on seismic performance. However, limited guidance exists for integrating their results into a practical workflow for portfolio-level decision-making.

1.3 Need for an Integrated Workflow

Although both methodologies are well established individually, limited guidance exists for integrating ASCE 41 evaluation results into SP3 portfolio assessments. In practice, engineers must determine how deficiencies identified during Tier 1 and Tier 2 evaluations should influence SP3 model development, performance objective selection, and interpretation of results. This lack of a documented workflow reduces consistency between projects and limits broader adoption of probabilistic loss assessment during capital planning.

This paper addresses that gap by presenting a practical methodology for combining ASCE 41 evaluations with SP3 loss modeling for existing building portfolios. Rather than replacing code-based seismic evaluations, the workflow leverages them to develop more meaningful risk metrics that support investment decisions.

1.4 Scope of This Paper

The methodology is demonstrated through a municipal portfolio assessment performed for a City in California. The project included 15 buildings representing multiple structural systems, occupancies, and seismic risk categories. A second case study is included with further examples of implementation of the methodology with a private client. A third case study applied the methodology to an existing instrumented building damaged in a strong earthquake, reinforcing the discussion of an iterative assessment process for complex or critical buildings.

The paper presents:

- A multi-step workflow for integrating ASCE 41 Tier 1 and Tier 2 evaluations with SP3 probabilistic loss assessment;
- Approaches for addressing deficiencies identified by ASCE 41 that are not directly represented within SP3;
- Considerations for selecting appropriate performance objectives for different owner priorities; and
- Methods for communicating technical findings to engineers, facility managers, governing city councils and county boards of supervisors, and executive decision-makers.

The discussion is limited to portfolio-level assessments intended to support capital planning. Building-specific Tier 3 nonlinear analyses, project-specific FEMA P-58 studies, custom fragility development, and insurance underwriting applications are outside the scope of this paper and remain appropriate where project-specific investment decisions warrant more detailed analysis.

2.0 Background

2.1 ASCE/SEI 41 Evaluation Procedures

ASCE/SEI 41-23 establishes nationally recognized procedures for the seismic evaluation and retrofit of existing buildings. The standard defines performance objectives as combinations of hazard level and structural performance level and provides three levels of evaluation with increasing analytical rigor.

- Tier 1 consists of a checklist-based screening procedure intended to rapidly identify potential deficiencies.
- Tier 2 evaluates identified deficiencies through component-specific criteria.
- Tier 3 employs detailed analytical procedures, including nonlinear methods where appropriate, to evaluate complete building response.

For portfolio-level assessments, Tier 1 screening supplemented by targeted Tier 2 evaluations often provides sufficient information to identify significant structural deficiencies while maintaining practical project schedules and budgets.

A key characteristic of ASCE 41 is that evaluations are performed at the component level. Individual structural components either satisfy or fail prescribed acceptance criteria for the selected performance objective. The resulting deficiency list provides a technically defensible basis for identifying retrofit needs and developing conceptual strengthening strategies. This approach is well suited for evaluating structural performance and demonstrating compliance with a selected performance objective.

For many owner decisions, however, a deficiency list alone does not provide sufficient context. While it identifies *what* deficiencies exist, it does not indicate which deficiencies represent the greatest financial or operational risk, how those deficiencies affect functional recovery following an earthquake, or which retrofit measures are likely to provide the greatest benefit. Consequently, buildings with similar ASCE 41 findings may warrant different investment strategies depending on their expected losses, operational importance, and long-term ownership objectives. Translating component-level deficiencies into consequences that owners can compare across a portfolio is one of the primary motivations for integrating ASCE 41 evaluations with probabilistic loss assessment.

2.2 FEMA P-58 and Probabilistic Loss Assessment

FEMA P-58 provides a probabilistic framework for estimating earthquake consequences in terms meaningful to owners and stakeholders. Rather than evaluating compliance with a performance objective, the methodology estimates repair cost, functional recovery, casualties, and unsafe placard probability by combining predicted structural response with component fragility and consequence functions.

Conventional FEMA P-58 assessments require nonlinear response-history analyses over multiple earthquake intensities to develop statistical distributions of engineering demand parameters. Although this produces highly detailed loss estimates, the computational effort generally limits application to individual buildings or projects involving major capital investment.

2.3 SP3 Portfolio-Level Implementation

The Seismic Performance Prediction Program (SP3) provides a practical implementation of the FEMA P-58 methodology for projects where building-specific nonlinear response-history analyses are not warranted. Rather than requiring engineers to develop a nonlinear analytical model for each building, SP3 uses the Structural Response Prediction Engine (SRPE), which predicts engineering demand parameters from a database of normalized nonlinear analyses representing a range of structural archetypes. Building-specific modifiers are then applied to estimate the expected structural response without requiring project-specific nonlinear modeling.

This approach substantially reduces the computational effort required to perform probabilistic loss assessments while maintaining consistency with the FEMA P-58 consequence framework. As a result, SP3 is well suited for portfolio-scale assessments, schematic design studies, and other applications where evaluating many buildings efficiently is an important consideration. For highly irregular structures, buildings with uncommon structural systems, or projects where investment decisions warrant a higher level of analytical rigor, a project-specific FEMA P-58 assessment using nonlinear response-history analysis may remain the more appropriate approach.

At first glance, SP3 can have something of a "black-box" impression. However, the underlying methodology is firmly rooted in FEMA P-58, and understanding the assumptions incorporated into the program is important when interpreting the results. While portions of the software remain proprietary, the primary inputs and their influence on the overall model are generally transparent, allowing engineers to evaluate whether the predicted structural response is representative of the building being assessed.

Unlike ASCE 41, which identifies structural deficiencies at the component level, SP3 translates expected building response into consequence-based performance metrics. These metrics describe earthquake performance in terms that are often more meaningful to owners and decision-makers because they quantify the financial and operational implications of earthquake damage rather than simply identifying where deficiencies exist.

The main metrics used throughout this paper are summarized below.

2.3.1 Loss Metrics

SP3 reports several complementary measures of financial loss because no single metric completely describes seismic risk.

Probable Maximum Loss (PML) has historically been the most common metric for expressing seismic risk in the insurance and commercial real estate industries. While PML remains widely recognized, ASTM E2026 recommends reporting Scenario Expected Loss (SEL) and Scenario Upper Loss (SUL), and these metrics are increasingly replacing PML in seismic risk assessments. All three metrics express expected repair cost as a percentage of the building replacement value.

The replacement cost of a building is not equivalent to the building's estimated value. Replacement costs account for the demolition of the existing building and site debris removal, often increasing costs by 20%-30%. FEMA P-58 sets a threshold where the building is likely to be replaced instead of repaired at loss of 50% or more. (However, recent studies have found that 40% may be more accurate.) Factors affecting this threshold include building age, occupancy, status as historic or civic landmark, economic health of the surrounding area, and profitability.

Scenario Expected Loss (SEL) represents the expected repair cost associated with a specific earthquake scenario and is expressed as a percentage of the building replacement value. It is defined as the mean percentage loss calculated based on the repair/replacement cost of the building. Because it evaluates the consequences of (many simulations of) a single event, SEL is particularly useful for comparing retrofit alternatives or understanding the potential impact of a design-level earthquake. Similarly, Scenario Upper Loss (SUL) is the 90^{th} percentile loss—the loss percentage that will not be exceeded in 90% of the simulations. In commercial real estate lending, decision-makers will typically either require earthquake insurance or otherwise not invest in a property for a PML that exceeds a certain threshold, often 20% SEL for an event with a 10% chance of exceedance in 50 years.

Expected Annual Loss (EAL) approaches the problem from a different perspective. Rather than considering a single earthquake, EAL estimates the average annual repair cost expected over the building's service life by accounting for both the probability and severity of all future earthquakes. This makes EAL particularly useful for evaluating long-term financial risk and performing benefit-cost comparisons between retrofit alternatives. While scenario-based metrics such as SEL illustrate the consequences of an individual earthquake, EAL provides a broader measure of expected seismic risk over time. One use for annualized loss is for determining insurance premiums. While scenario-based metrics like SEL and SUL are valuable, the building is expected to resist many different ground motions, and the annualized loss provides a more versatile metric than evaluating a single ground motion.

Together, these metrics provide complementary perspectives on seismic performance. As demonstrated later in this paper, evaluating both SEL and EAL often provides additional insight because a retrofit strategy that performs well for a specific earthquake scenario may not produce the same level of benefit when viewed over the anticipated ownership period.

2.3.2 Functional Recovery

Although repair costs are often the most familiar measure of earthquake loss, they do not fully describe how earthquake damage affects building operations. Functional recovery estimates the time required for a building to return to its intended use following an earthquake by considering the combined effects of structural damage, nonstructural damage, utility disruptions, and repair sequencing. For facilities that support emergency response, public services, or critical business operations, functional recovery may be as important as repair cost when evaluating seismic risk and retrofit priorities. Conversely, certain buildings may be able to return to their "intended use" even though significant damage remains. For example, lack of HVAC may not be a functionality requirement in certain climates, or boarded windows may be acceptable for function in some occupancies.

Additional outputs, including Unsafe Placard Probability and indicative USRC Safety, Damage, and Recovery ratings, provide further measures of expected building performance and can be particularly useful when communicating results to facility managers, executive leadership, and other nontechnical stakeholders.

3.0 Methodology

ASCE 41 and SP3 each provide valuable insight into the seismic performance of existing buildings, but they answer different questions. ASCE 41 identifies structural deficiencies relative to a selected performance objective. SP3 estimates the consequences of those deficiencies in terms of repair costs, functional recovery, life safety, and annualized loss. Used together, they provide owners with a more complete understanding of seismic risk and a stronger basis for making retrofit decisions.

The workflow presented here evolved through several portfolio-level assessments where owners needed more than a list of structural deficiencies—they needed practical information to help prioritize limited capital funds. While every project presents unique challenges, the overall approach proved adaptable across a range of building types and owner objectives. The discussion that follows outlines the workflow before demonstrating its application through the case studies presented later in the paper.

The workflow consists of seven general steps:

1. Establish performance objectives.
2. Document existing building conditions.
3. Evaluate existing risk.
4. Perform additional investigation.
5. Develop retrofit strategies.
6. Quantify retrofit benefits and potential losses.
7. Communicate findings in a usable format for the owner.

3.1 Establish Performance Objectives

Selecting a performance objective is the first step in any ASCE 41 evaluation, but the discussion can look very different depending on whether the project is driven by a mandatory retrofit requirement or a voluntary investment in seismic risk reduction.

For mandatory retrofit programs, the required performance objective is often established by the governing ordinance or policy, leaving relatively little flexibility in the evaluation criteria. Even in these cases, however, owners may choose to exceed the minimum requirements when the additional investment aligns with broader resilience, operational, or risk

management objectives. Once a project is underway, the incremental cost of pursuing enhanced performance may be small compared with the overall cost of mobilization, demolition, and disruption associated with the retrofit itself.

Voluntary retrofit projects present a different challenge. In these cases, the owner has already decided to invest in improving the building's seismic performance, but the appropriate performance objective is not prescribed. Instead, it is established collaboratively by the owner and design team. Because most owners are not familiar with seismic performance objectives or the implications of different hazard levels, one of the engineer's first responsibilities is to clearly explain the available options and the tradeoffs associated with each.

Performance objectives should ultimately reflect not only the structural characteristics of the building, but also the owner's expectations for post-earthquake performance. While ASCE 41 establishes Basic Performance Objectives based primarily on Risk Category, many buildings serve operational or community functions that extend beyond their occupancy classification. Understanding those expectations often requires more than reviewing drawings or building records.

Discussions with facility managers and owner representatives frequently reveal operational needs, future plans, or community functions that are not immediately apparent from the available documentation. Topics commonly include:

- staffing and occupancy;
- critical equipment or hazardous materials;
- planned renovations or capital improvements;
- deferred maintenance;
- previous seismic upgrades;
- expected post-earthquake/emergency operations;
- historic relevance or cultural significance;
- community recovery functions and importance; and
- acceptable levels of disruption during retrofit.

These discussions provide context for the engineering evaluation that follows and often help explain later decisions when technical findings are weighed alongside operational priorities. They also establish the foundation for subsequent discussions of repair costs and functional recovery, both of which depend on understanding how the owner expects the building to perform following a major earthquake.

3.2 Document Existing Building Conditions

With the performance objectives established, the next step is developing a clear understanding of the building in its current condition.

Available drawings, previous reports, and geotechnical information provide the starting point, but site observations remain an important part of the evaluation. In addition to confirming the structural systems, site visits provide an opportunity to document previous modifications, existing damage, and nonstructural components that may influence repair costs or functional recovery.

Although the structural evaluation naturally focuses on the lateral-force-resisting system, documenting significant nonstructural components during the site visit often proves worthwhile. Much of a building's repair cost following an earthquake is associated with nonstructural damage, making those observations valuable when developing the corresponding SP3 model.

The objective of this phase is to establish a reliable representation of the building before evaluating either its structural performance or its expected earthquake losses.

3.3 Evaluate Existing Risk

Once the existing building has been documented, the initial evaluation can begin. A Tier 1 evaluation provides an efficient means of identifying significant structural deficiencies relative to the selected performance objective.

The Tier 1 findings can then be paired with a preliminary SP3 assessment representing the building in its existing condition. Where appropriate, significant deficiencies identified during the ASCE 41 evaluation may be reflected in the SP3 model so that the resulting loss estimates better represent the building being evaluated. Viewed together, the two assessments begin to tell a more complete story. ASCE 41 identifies where the building is vulnerable, while SP3 helps quantify what those vulnerabilities mean in terms of expected repair costs, recovery time, and long-term seismic risk.

For individual buildings, these preliminary results help determine whether additional investigation is warranted. For portfolios, they also provide a practical basis for comparing buildings and identifying facilities that merit further evaluation (i.e. ASCE 41 Tier 2 or 3) or consideration during capital planning.

For example, in a warehouse with exposed framing, an out-of-plane wall anchorage deficiency and a foundation overturning deficiency may both be identified during a Tier 1 evaluation, but they do not necessarily represent the same level of risk or require equivalent retrofit effort. The out-of-plane wall anchorage deficiency may be corrected relatively inexpensively with minimal disruption to day-to-day operations. In contrast, strengthening the foundation to address overturning demands may require extensive demolition, significantly higher construction costs, and temporary relocation of building occupants during construction.

While ASCE 41 generally anticipates that Tier 1 deficiencies will be investigated further through a Tier 2 evaluation, understanding the owner's priorities provides valuable context for determining where additional engineering effort is likely to have the greatest impact. As discussed in the following sections, combining those engineering findings with probabilistic loss assessment helps distinguish deficiencies that warrant more detailed evaluation from those that can be addressed through relatively straightforward retrofit measures.

3.4 Perform Additional Investigation

Deficiencies identified in the Tier 1 screening can be further evaluated using the Tier 2 procedures. This step often involves creation of a three-dimensional model to determine the distribution of load to the various components of the building. When a 3D model is constructed, the results of the building analysis can be utilized to improve the results of the SP3 predictions. Notably, building periods and mode shapes from analysis can be added to the SP3 model inputs. The building model will also permit evaluation of building irregularities. The irregularities are classified as “none,” “moderate,” or “extreme” and are added as inputs to the SP3 analysis.

The Tier 1 deficiencies are evaluated at a component level using demands from the analysis. Where a deficiency is confirmed using the Tier 2 procedures, this is recorded for consideration for retrofit. Depending on the severity of the deficiency, particularly considering the year of the original design code, the engineer may consider adjustment of the component fragility in SP3. This requires judgement and/or calculations to justify. Adjustment can be made to the capacity of the component strength relative to what the original design code would have required, or alternate components can be specified.

The results of the building analysis (period, mode shapes, irregularities, and component fragility adjustments) should then be input into the SP3 analysis and the existing condition analysis rerun. An example of how these additional inputs can impact the results of the SPRE estimates are included in Section 7.

3.5 Develop Retrofit Strategies

Once the initial assessment is complete, attention shifts from understanding the existing building to exploring opportunities for improvement. Tier 2 evaluations provide additional insight into the significance of deficiencies identified during the

Tier 1 screening and, in some cases, demonstrate that further retrofit is unnecessary or undervalued. Where deficiencies remain, conceptual retrofit strategies can be developed and budgetary construction costs prepared.

Rather than evaluating only a single "fully retrofitted" building, it is often useful to consider individual retrofit measures independently. Developing conceptual retrofit scopes and corresponding cost estimates creates a menu of potential improvements that can later be compared with changes in repair costs, functional recovery, and other SP3 loss metrics. This provides owners with greater flexibility when capital budgets do not support comprehensive seismic retrofit.

Where the retrofit strategy incorporates additional strength and stiffness that alters the fundamental building period or irregularities, updated building responses should be incorporated into the “retrofit” SP3 analysis.

3.6 Quantify Retrofit Benefits

With conceptual retrofit strategies established, the SP3 models can be updated to reflect the proposed improvements.

Evaluating existing and retrofitted conditions side by side allows changes in repair costs, functional recovery, annualized loss, and other performance metrics to be compared directly with estimated construction costs. Viewing the results this way shifts the discussion from *whether* deficiencies exist to *what value* each retrofit strategy provides.

How the results are outlined should vary based on the building occupancy and the client’s needs. In the case of voluntary evaluations, some example needs include:

- Determining whether insurance is worthwhile for managing seismic risk.
- Determining seismic risk of an existing building and whether that risk is acceptable for the planned use or if the building should be upgraded or sold.
- Performing benefit-cost studies to determine reasonable investments for improved seismic performance.

For some owners, expected repair costs may be the primary consideration. Others may place greater emphasis on maintaining operations after an earthquake or reducing recovery time for critical facilities. Reviewing multiple performance metrics allows the engineering evaluation to better reflect the owner's priorities rather than relying on a single measure of performance.

3.7 Communicate Findings

The final step is presenting the results in a way that supports informed decision-making. The level of detail, format, and performance metrics will naturally vary depending on the audience. Facility managers, engineers, executive leadership, and elected officials may all view the same information through different lenses.

For portfolio assessments, concise summaries that combine engineering findings with repair costs, loss estimates, and recovery metrics often prove more useful than detailed technical discussions for every building. The objective is not to simplify the engineering, but to present it in a form that allows owners to compare alternatives, understand tradeoffs, and make informed decisions about future investments.

4.0 Case Study 1 – Municipal Portfolio

The workflow described in Section 3 was applied in 2024 as part of a portfolio-level seismic assessment for a City in Northern California. The City initiated the project to better understand the seismic risk associated with its municipal facilities and to support future capital planning and emergency preparedness.

The assessment ultimately included 15 buildings totaling more than 90,000 square feet, representing a range of occupancies, structural systems, and Risk Categories. The portfolio included fire stations, the police station, City Hall, maintenance facilities, community buildings, and other municipal infrastructure. Rather than focusing on a single building,

the objective was to understand the relative risk across the portfolio and provide City leadership with information that could help prioritize future investment and related decisions.

Table 1 summarizes the buildings included in the assessment and their corresponding performance objectives.

Table 1 - Buildings evaluated as part of the City inventory

Building	Date of Construction	Building Type	Risk Category	Evaluated Performance Objective
Harbor Master Building	1989	W1	II	BSE 1E – LS BSE 2E – CP
City Hall	Original – 1954 Addition – 1971	S1A & C2A	III	*BSE 1E – IO *BSE 2E - LS
Corporation Yard	Unknown	C2A	II	BSE 1E – LS BSE 2E – CP
Fire Station A	1980	W2	IV	BSE 1E – IO BSE 2E - LS
Fire Station B	Original – 1971 Addition - 1991	RM1	IV	BSE 1E – IO BSE 2E - LS
Police Station	Original – Unk. Addition - 1985	W2	IV	BSE 1E – IO BSE 2E - LS
Office	2003	RM2 & S2A	III	BSE 1E – DC BSE 2E – LMS
Community Center	1987	RM1 & W2	III	*BSE 1E – IO *BSE 2E - LS
Senior Center	Original – 1988 Addition – 2004	RM1 & W2	II	BSE 1E – LS BSE 2E – CP
Teen Center	1959	RM1	III	BSE 1E – DC BSE 2E – LMS
Sports/Activity Center	1991	RM1	II	BSE 1E – LS BSE 2E – CP
Transit Center	Original – Unk. Addition - 2013	S2A	II	*BSE 1E – DC *BSE 2E – LMS
Historic Museum	1947	URM	III	BSE 1E – DC BSE 2E – LMS
Parking Garage	1985	C2	II	BSE 1E – LS BSE 2E – CP
Police Station Storage	Unknown	W1	IV	BSE 1E – IO BSE 2E – LS

*Denotes an enhanced performance objective based on engagement meetings

4.1 Defining the Evaluation Strategy

As discussed in Section 3, the project began with engagement meetings to better understand how each facility supported City operations before, during, and after a major earthquake. While many buildings fit naturally within the Basic Performance Objectives prescribed by ASCE 41, several facilities served operational roles that extended beyond their occupancy classification.

Meetings with City staff focused on day-to-day building use, emergency response responsibilities, planned capital improvements, deferred maintenance, and anticipated post-earthquake operations. Existing drawings and geotechnical

reports were reviewed beforehand to help guide these discussions and identify topics requiring additional clarification during site visits.

Those conversations ultimately influenced the selected performance objectives for several buildings. City Hall was assigned an enhanced performance objective because of its anticipated role in coordinating community recovery and distributing disaster relief resources. The Transit Center was identified as a backup Emergency Operations Center housing critical communications equipment, while the Community Center was expected to serve as a post-disaster shelter and resource center. Buildings without additional operational demands generally retained the Basic Performance Objectives associated with their Risk Category.

By the conclusion of this phase, the project team had established both the technical basis for the evaluations and a clear understanding of the City's priorities. Those priorities became an important reference point as the engineering findings were developed and interpreted throughout the remainder of the project.

4.2 Evaluating the Portfolio

Following the engagement phase, each building was documented through site observations and evaluated using ASCE 41 Tier 1 procedures. Preliminary SP3 assessments were then completed to estimate repair costs, functional recovery, and other performance metrics for the existing building conditions.

The preliminary evaluations served two purposes. First, they identified significant structural deficiencies within each building. Second, they provided a consistent basis for comparing seismic risk across the entire portfolio. Rather than advancing every facility into more detailed analysis, the initial findings helped identify where additional engineering effort was likely to provide the greatest value. Table 2 summarizes a portion of the preliminary findings matrix developed during the assessment.

The preliminary assessment identified City Hall and the Historic Museum as the highest priorities for additional evaluation. Both buildings combined significant structural deficiencies with important community functions and value, making them logical candidates for more detailed investigation.

Tier 2 evaluations were then performed where appropriate to determine whether deficiencies identified during the initial screening could be resolved through additional investigation or would require retrofit. Where deficiencies remained, conceptual retrofit strategies and planning-level construction cost estimates were developed. Evaluating individual retrofit measures separately, rather than considering only a comprehensive seismic upgrade, provided greater flexibility for comparing cost, constructability, and anticipated reduction in seismic risk.

Figure 1 illustrates an example of conceptual retrofit details developed during the study.

Table 2 - Portion of Building Preliminary Finding Matrix

Building	Building Type	Relevant Tier 1 Deficiencies	Seismic Risk
Harbor Master Building	W1	No significant deficiencies	Low
City Hall	S1A & C2A	1. Moment frame beam to column connections are insufficient 2. Moment frame beams and columns are insufficient. 3. Moment frame column anchorage is insufficient. 4. Roof diaphragm connection to moment frame beams is insufficient.	High
Corporation Yard	C2A	No significant deficiencies	Low
Fire Station A	W2	1. Narrow shear walls are insufficient	Moderate
Fire Station B	RM1	1. CMU wall anchorage to roof is not present for a majority of the building	High
Police Station	W2	1. CMU wall anchorage to roof is not present for selection portions of the building.	Moderate
Office	RM2 & S2A	1. Braced frame columns are insufficient 2. Braced frame connections are insufficient 3. Braced frame chevron beams are insufficient	Moderate
Community Center	RM1 & W2	1. CMU wall anchorage to roof is insufficient 2. Interior wood shear walls are insufficient 3. Seismic gap is insufficient	Moderate
Senior Center	RM1 & W2	No significant deficiencies	Low
Teen Center	RM1	1. Girder to pilaster wall anchorage connection is not present	High
Sports/Activity Center	RM1	1. CMU wall anchorage to roof is insufficient	High
Transit Center	S2A	1. Roof diaphragm to steel frame connection is insufficient. 2. Steel frame panel zones are insufficient	Moderate
Historic Museum	URM	1. URM wall anchorage to roof is insufficient 2. Wood ledger connections are insufficient 3. URM height to thickness ratios are insufficient 4. URM shear stress capacity is insufficient	High
Parking Garage	C2	No significant deficiencies	Low
Police Station Storage	W1	No significant deficiencies	Low

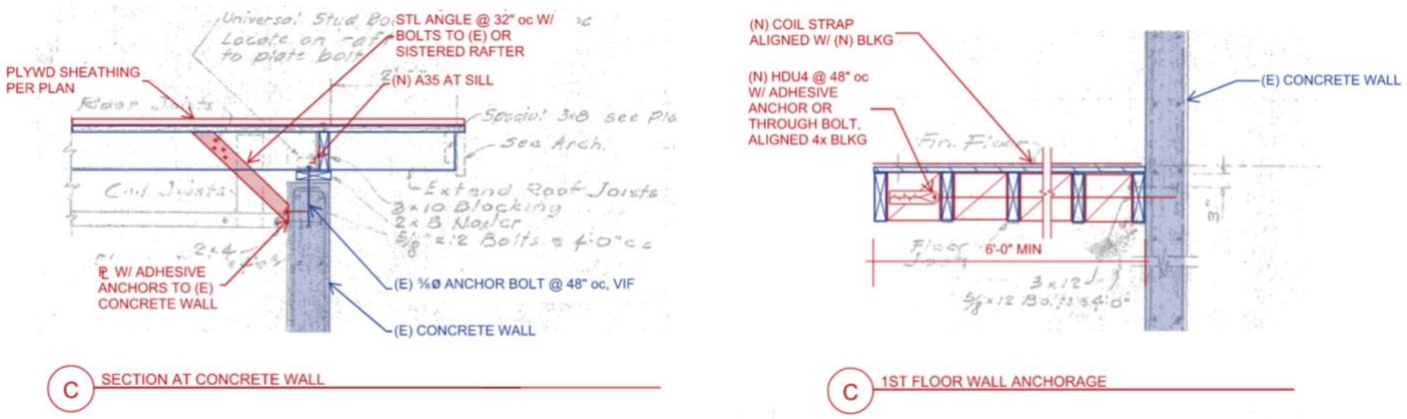


Figure 1 - Schematic retrofit details for out of plane wall anchorage

4.3 City Hall – Balancing Cost, Risk, and Recovery

City Hall illustrates how combining structural evaluation with probabilistic loss assessment can support more informed retrofit decisions.

Planning-level construction costs were developed for a comprehensive seismic retrofit totaling approximately $5 million. The estimate included approximately $600,000 for out-of-plane wall anchorage, $2.0 million for moment frame member and connection strengthening, $1.0 million for roof diaphragm strengthening, and $1.4 million for column anchorage improvements.

Reviewing these retrofit measures individually proved just as valuable as evaluating the full retrofit. Column anchorage strengthening represented a significant portion of the total construction cost and was considered too intrusive to pursue. In contrast, roof diaphragm strengthening was not considered an immediate capital priority because it could be completed as part of a future reroofing project under the City's deferred maintenance program. This provided the City with flexibility to coordinate seismic improvements with planned maintenance activities while focusing near-term capital funding on higher-priority upgrades.

To evaluate the relative benefit of each strategy, four SP3 models were developed representing the existing building, the full retrofit, strengthening of the out-of-plane wall anchorage, and strengthening of the moment frame members and beam-column connections. A summary of the resulting loss metrics is presented in Table 3. Unless otherwise noted, the reported results correspond to the 10% in 50-year ground motion.

Table 3 - Summary of Loss Metrics for City Hall

	City Hall - Unretrofitted	**City Hall – Out of Plane Wall Anchorage Retrofit**	**City Hall – Steel Moment Frames Retrofit**	**City Hall - Full Retrofit**
Cost of Retrofit	$0	$600,000	$2,000,000	$5,000,000
SEL Percentage	23.90%	13.40%	16.00%	7.30%
SEL Loss	$5,975,000	$3,350,000	$4,000,000	$1,825,000
SUL Percentage	43.30%	22.60%	27.40%	16.00%
SUL Loss	$10,825,000	$5,650,000	$6,850,000	$4,000,000
Annualized Loss	$50,490	$35,563	$38,764	$14,716
Reoccupancy	4.9 Months	3.4 Months	3.9 Months	1 Month
Functional Recovery	8.6 Months	8.3 Months	8.3 Months	5.7 Months
Full Recovery	8.6 Months	8.3 Months	8.4 Months	6.3 Months

When viewed using Scenario Expected Loss (SEL), the projected reduction in repair costs exceeded the estimated retrofit cost, suggesting that portions of the retrofit could be economically justified if the scenario earthquake were to occur. However, SEL evaluates the consequences of a single event and does not account for the probability of that event occurring during the anticipated ownership period.

Expected Annual Loss (EAL) provides a different perspective by incorporating the full range of earthquake hazard over time. Table 4 compares the annualized losses and corresponding net present value of the retrofit alternatives assuming a 7% rate of return. Under these assumptions, none of the retrofit options produced a positive net present value over the anticipated ownership period, indicating that the seismic improvements could not be justified on economic considerations alone.

Table 4 - Annualized Loss Summary for City Hall

	City Hall - Unretrofitted	City Hall – Out of Plane Wall Anchorage Retrofit	City Hall – Steel Moment Frames Retrofit	City Hall - Full Retrofit
Cost of Retrofit	$0	$600,000	$2,000,000	$5,000,000
Annualized Loss	$50,490	$35,563	$38,764	$14,716
Annualized Loss Savings from Retrofit	N/A	$14,927	$11,726	$35,774
Net Present Value (10 Years)	N/A	$104,841	$82,359	$251,262
Net Present Value (20 Years)	N/A	$158,137	$124,225	$378,990
Net Present Value (30 Years)	N/A	$185,230	$145,508	$443,921
Net Present Value (40 Years)	N/A	$199,002	$156,328	$476,929
Net Present Value (50 Years)	N/A	$206,004	$161,828	$493,708
Net Present Value (Indefinite)	N/A	$213,243	$167,514	$511,057

The engagement meetings conducted at the outset of the project provided important context for interpreting those results. City Hall was identified as a civic hub and a potential disaster relief distribution center following a major earthquake. As a result, improvements in reoccupancy, functional recovery, and overall community resilience became important considerations alongside repair costs. Rather than pursuing a comprehensive retrofit, the City began evaluating combinations of partial retrofit measures that better aligned with both operational priorities and available capital funding. At the time of the assessment, the City was also considering replacement of City Hall within approximately ten years because the existing facility no longer met its long-term operational needs. The cost-benefit analysis therefore provided a framework for evaluating whether selective seismic improvements remained appropriate should that replacement schedule change or be delayed.

4.4 Supporting Capital Planning

The project concluded with presentations to City leadership summarizing the engineering findings and their implications for future capital planning.

The objective was not to recommend retrofit for every building or to rank facilities solely by structural deficiencies. Instead, the evaluation provided a consistent basis for comparing retrofit, replacement, deferred maintenance, and continued use across the City's building portfolio. For some facilities, the findings supported additional seismic investment. For others, the results suggested that continued monitoring or eventual replacement represented more appropriate long-term strategies.

Perhaps the greatest value of the assessment was that it changed the conversation from identifying deficiencies to evaluating options. By combining structural evaluation with probabilistic loss assessment, the City gained a clearer understanding of where seismic risk existed, what those risks meant in practical terms, and how future investments could be aligned with operational priorities and available capital funding.

5.0 Case Study 2 – Private Portfolio

The workflow was also applied to two campus-wide seismic assessments for a private client in Northern California totaling more than two million square feet of building space. While the engineering evaluation closely followed the methodology described in Section 3, the project objectives—and ultimately the presentation of the results—differed significantly from the municipal assessment.

Previous evaluations for the campuses had been completed using ASCE 41-06 and were written primarily for a technical audience. The objective of this effort was to update those assessments and present the findings in a format that could support executive-level decision-making. Early discussions with the client established three priorities:

- Reduce portfolio risk;
- Prioritize limited capital funding; and
- Communicate the findings clearly to executive leadership.

The engineering evaluation remained largely unchanged. However, the way the results were communicated was updated significantly.

5.1 Presenting Risk to Executive Leadership

The project began with site visits to verify existing conditions and document changes that had occurred since the previous evaluations. Tier 1 screenings and targeted Tier 2 evaluations were updated where appropriate, and portfolio-level SP3 assessments were performed to estimate repair costs, functional recovery, and other performance metrics across the campuses.

Unlike the City project, however, the intended audience was not a group of engineers or facility managers. The findings were expected to support executive leadership, and the recommendations needed to be understood without extensive technical discussion. The results had to be presented to a non-technical audience such that clarifications would not be necessary and a recommendation was clear. For that reason, the final presentation focused on three complementary measures of performance:

- USRC building ratings;
- Expected Annual Loss (EAL); and
- Scenario Expected Loss (SEL).

The USRC Rating system communicates the FEMA P-58 results in a simple star rating system which provides a concise and clear understanding of the building safety, damage, and recovery down time considering the probability of an earthquake event in the next 30 to 50 years. All three dimensions are summarized with a 1 to 5 star rating system as shown in Figure 2. Together, these metrics provided a concise summary of building performance, expected financial loss, and recovery potential while remaining grounded in the underlying engineering evaluation.



Figure 2 - USRC Building Star Ratings

5.2 Prioritizing Investment Across the Portfolio

Rather than reviewing buildings individually, the results were organized to help leadership understand relative risk across the portfolio.

Expected Annual Loss (EAL) and Scenario Expected Loss (SEL) were developed for each building, allowing facilities to be grouped according to their overall seismic risk and potential benefit from future mitigation. The scenario evaluated was limited to a single M6.7 event. To produce these loss estimates, SP3 needed a corresponding ground shaking intensity, which was estimated using the NGA West2 Ground Motion Prediction Equations (GMPEs) based on the soil type and fault characteristics at each campus. The assumptions used in the GMPEs were provided in an appendix for transparency, but the use of the M6.7 event was intentional—according to the Uniform California Earthquake Rupture Forecast 3 (UCERF3), there is a 72% chance that an earthquake measuring magnitude 6.7 will occur in the San Francisco Bay Area within the next 30 years. The probability of that event occurring on the governing fault for a particular site is less than 72% and expanded probabilities were provided in an appendix.

Presenting the information graphically made it possible to quickly identify buildings where future investment would provide the greatest reduction in risk. Figure 3 is a graph that compares loss estimates for each building and illustrates how to group buildings into "bins" to prioritize seismic mitigation investments. Grouping into the bins requires a combination of quantitative metrics, engineering judgement, and an understanding of how the client views risk. A building with high risk to human life may be given priority over one with higher financial loss metrics.

The simplified presentation proved effective because it allowed executive leadership to focus on investment priorities rather than the details of individual structural deficiencies. The engineering evaluation remained the foundation of the recommendations, but the discussion shifted from component-level deficiencies to portfolio-level decision-making.

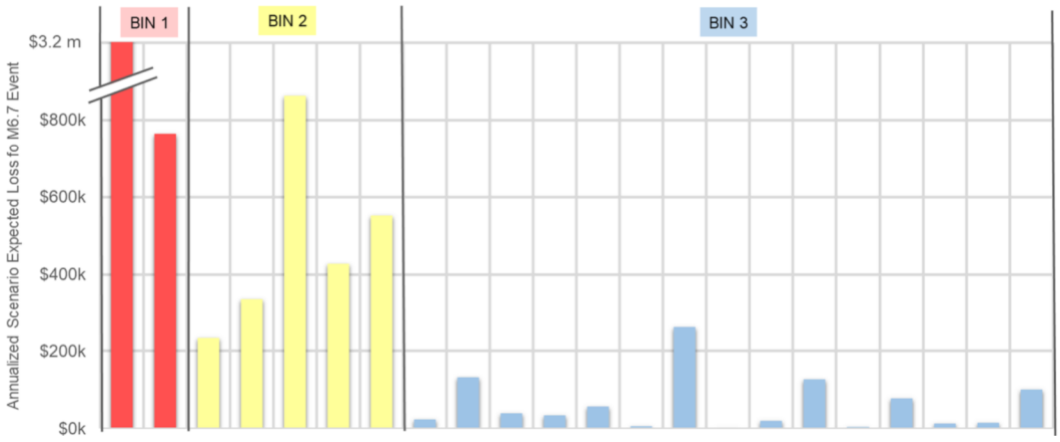


Figure 3 - Scenario Expected Loss (SEL) totals by building

Although the municipal and private portfolios differed substantially in size, occupancy, and decision-making process, the underlying workflow remained consistent. The primary difference was not the engineering—it was the audience. The City client benefited from an interactive discussion of individual buildings and retrofit options, while the private client required a concise summary that clearly communicated portfolio risk and investment priorities.

Together, the two case studies demonstrate that the workflow can be adapted to different owners without changing the underlying engineering process.

6.0 Discussion

The two case studies presented in this paper demonstrate that integrating ASCE 41 evaluations with probabilistic loss assessment provides information that neither methodology offers independently. ASCE 41 establishes where structural deficiencies exist and identifies potential retrofit measures. SP3 helps place those deficiencies in the broader context of repair costs, functional recovery, life safety, and long-term seismic risk. Together, they provide owners with a more complete basis for evaluating seismic investment decisions.

Perhaps more importantly, the combined approach changes the conversation between the engineer and the owner. Rather than focusing solely on whether a building satisfies a particular performance objective, the discussion expands to include how different retrofit strategies affect cost, recovery, and long-term operational goals. The answer will differ from project to project, but the workflow provides a consistent framework for evaluating those tradeoffs using engineering data that owners can understand and apply.

Although the methodology remained largely unchanged between the municipal and private portfolios, the way the results were communicated differed considerably. Technical audiences generally preferred detailed engineering findings and opportunities for discussion, while executive leadership responded more effectively to concise summaries that clearly communicated relative risk and investment priorities. In both cases, however, the engineering evaluation remained the foundation of the recommendations.

6.1 Engineering Judgement and Loss Modeling

One of the more valuable observations from these projects was that developing a meaningful loss assessment requires more than simply entering building information into the software. As with any engineering model, the quality of the results depends on how well the model represents the building being evaluated.
For the projects presented here, reviewing the predicted structural response proved just as important as reviewing the resulting loss metrics. Fundamental period, base shear strength, interstory drift, and peak floor acceleration provided useful checkpoints for determining whether the model reasonably represented the expected building behavior before interpreting repair costs or recovery times.

The projects also highlighted the importance of engineering judgment when selecting model parameters. Characteristics such as construction quality, structural detailing, FEMA P-154 modifiers, and other building attributes can meaningfully influence the predicted response. Reviewing the sensitivity of those assumptions and comparing modified models with baseline results often provided additional confidence that the resulting loss estimates reasonably represented the building being evaluated.

The intent is not to suggest that every model requires extensive calibration. Rather, the projects demonstrated that engineering judgment remains an important part of the modeling process, particularly when evaluating existing buildings that differ from typical archetypes or have undergone previous modifications.

6.2 Modeling Partial Retrofit Strategies

Partial seismic strengthening is a common outcome of voluntary retrofit projects, particularly when improvements are coordinated with tenant improvements, deferred maintenance, or other planned capital projects. In practice, owners often choose to address selected deficiencies rather than pursue comprehensive retrofit.

Representing these improvements within SP3 requires thoughtful engineering judgment because individual retrofit measures do not always correspond directly with available modeling parameters. Depending on the retrofit strategy, modifications may be more appropriately represented through changes to component capacity, structural response characteristics, or other building attributes.

For the projects presented here, evaluating retrofit measures individually proved particularly valuable. Rather than comparing only existing and fully retrofitted buildings, separate models were developed for selected retrofit strategies so that changes in repair costs, functional recovery, and annualized loss could be compared directly with planning-level construction costs. This approach provided owners with greater flexibility when evaluating phased improvements or capital projects with limited budgets.

Although the specific modeling approach will vary from project to project, evaluating individual retrofit measures independently often provides a clearer understanding of where future investment is likely to provide the greatest benefit.

6.3 Collapse Considerations

Collapse probability warrants particular attention because it can have a disproportionate influence on predicted earthquake losses. Simulations resulting in collapse are generally treated as a total loss, making the underlying collapse assumptions an important contributor to expected repair costs and annualized loss.

SP3 estimates collapse probability using the FEMA P-154 Rapid Visual Screening methodology, which is derived from the HAZUS framework and is well suited to evaluating large building portfolios. Those assumptions provide a practical and consistent basis for rapid screening across many buildings.

Project-specific evaluations, however, often have access to considerably more information than is available during rapid screening. Detailed ASCE 41 evaluations, analytical models, and project-specific investigations may provide additional insight into expected building behavior that is not reflected in generalized collapse estimates. When evaluating individual buildings or major retrofit investments, engineers should understand how collapse assumptions influence the resulting loss estimates and consider whether project-specific information supports refinement of those assumptions.

The intent is not to suggest that one methodology is universally preferable to another. Rather, the projects presented here demonstrate that the appropriate level of modeling detail depends on the objectives of the evaluation. Portfolio screening and individual building assessments often require different balances between consistency, efficiency, and project-specific accuracy.

6.4 Limitations

The workflow presented in this paper is intended to complement—not replace—established engineering evaluation procedures. ASCE 41 remains the basis for evaluating existing buildings, and project-specific nonlinear analyses remain appropriate where the complexity of the structure or the significance of the investment warrants additional rigor.

Similarly, SP3 continues to evolve as new research, modeling approaches, and software capabilities become available. Existing buildings frequently contain characteristics that require engineering judgment when selecting model parameters or interpreting results, particularly where previous seismic strengthening or atypical structural systems are involved.

The projects presented here also demonstrate that quantitative loss metrics should be considered alongside broader project objectives. Repair costs, annualized loss, and functional recovery each provide valuable information, but no single metric should be expected to determine whether a retrofit is appropriate. Building function, anticipated ownership, operational priorities, available funding, and future capital plans all influence the final decision.

Ultimately, the value of the integrated workflow is not that it produces a single answer, but that it provides owners with a more complete understanding of the tradeoffs associated with different seismic investment strategies.

7.0 Validation of the Iterative Workflow

To validate the method presented in this paper, the Imperial County Services Building (ICSB) was evaluated using SP3 together with ASCE 41 Tier 1 screening and Tier 2 evaluation. The six-story reinforced concrete building was damaged in

the October 15, 1979 Imperial Valley earthquake, has been studied extensively in publicly available literature, and was recently included in a benchmarking study by the Applied Technology Council (ATC) comparing state-of-the-art ASCE 41 analysis methods against observed building performance. The results indicate that the modifications to the SRPE predictions described in this paper improve the reliability of the loss estimates, moving the predictions into closer agreement with both the nonlinear results of the ATC study and the observed performance.

The building, designed per 1967 UBC, has moment frames in the longitudinal direction and shear walls in the transverse direction. The full-length (85-foot) perimeter shear walls are discontinuous at the ground floor. Although the columns were detailed with well-confined plastic hinge regions, the ground floor slab was cast against the columns, restraining movement and forcing hinging upward. The building configuration is illustrated in Figure 4.

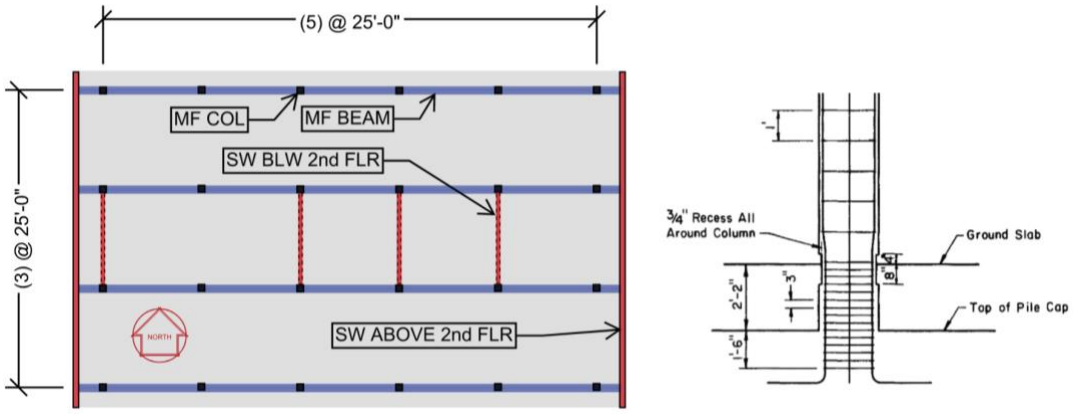


Figure 2 - Plan view of 2nd floor (left), elevation of column transv. reinforcing (right, courtesy of Kreger and Sozen, 1990)

An initial SP3 assessment was performed using building type (C1, C2), geometry, use, size, site class, response spectra from the recorded ground motion, and irregularities. The building was then screened using the ASCE 41 Tier 1 checklists against the BPOE (evaluated as CP at BSE-2E). Seven checklist items were found noncompliant: discontinuous vertical elements of the SFRS, changes in horizontal dimension of the SFRS greater than 30%, overturning ratio, column axial stress, column shear stress, column tie spacing, and wall shear stress.

A Tier 2 deficiency-based evaluation of the noncompliant items followed, using a three-dimensional ETABS model with stiffness modifiers per ASCE 41-17. The geometric irregularity required evaluation of the ground floor columns and walls using the LDP, with the columns below the discontinuous walls evaluated as force-controlled. The model produced elastic periods of 1.27 seconds in the longitudinal direction and 0.315 seconds in the transverse direction, and the Torsional Irregularity Ratio (TIR) computed by the linear static procedure was 1.39. The Tier 2 checks showed that the columns below the discontinuous walls are non-compliant, that shear demands exceed expected strengths for nearly all columns at the base, and that nearly all ground floor columns are shear controlled, unable to develop flexural hinges prior to large shear cracking.

Based on the Tier 2 results, the following modifications were made to the initial analysis SP3 analysis:

1. Elastic fundamental periods from ETABS were input into the structural properties table.
2. The ground floor building components were changed from the IMF columns auto-populated by SP3 to non-conforming MF, weak columns and strong joints.
3. The severity of the torsional irregularity was upgraded from moderate to extreme based on the computed TIR.

The modifications reduced the SEL from 44% to 25% and the SUL from 73% to 45%. The refined building inputs (period, irregularities, components) informed the SPRE, producing a more realistic estimate of the interstory drift ratio (IDR). As shown in Figure 5, the refined predictions are in much better agreement with the NDP results and the recorded building response. Lack of agreement for the SW direction at the ground floor can be attributed to the torsional irregularity.

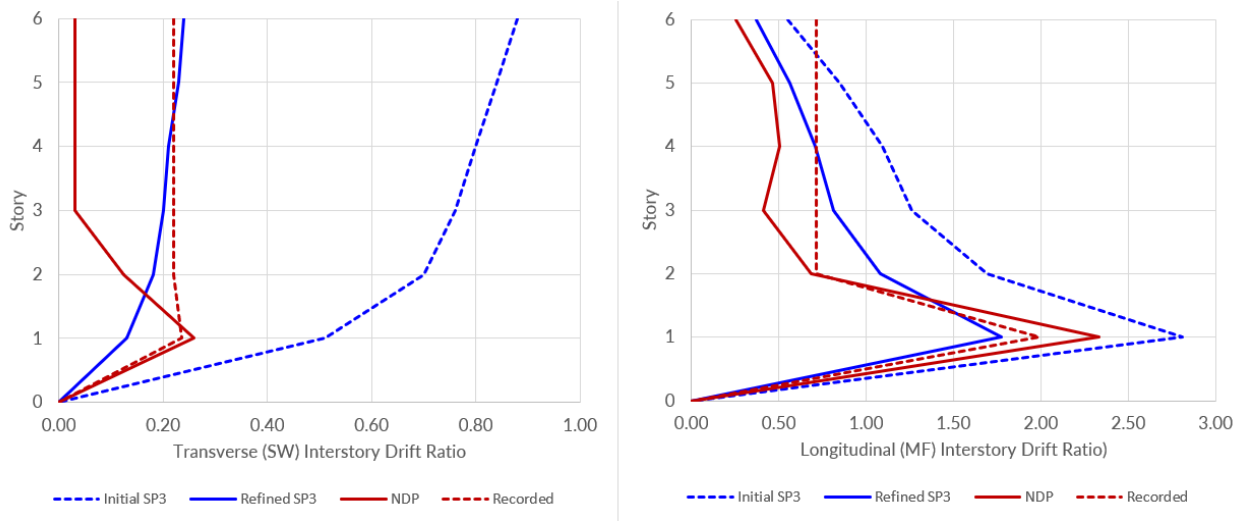


Figure 5 - Comparison of IDRs in transverse / shear wall direction (left) and longitudinal / moment-frame direction (right).

The observed damage was concentrated in the first-story columns, particularly at the eastern end of the building, which experienced combined shear and axial failures. Four of the 24 ground floor columns lost gravity capacity; several other columns had severe shear cracking. Observed damage agreed with the Tier 2 results.

These results are not meant to imply that SP3 approximations provide the reliability of a comprehensive nonlinear analysis. They do demonstrate the two central conclusions of this validation. First, critical information obtained from the Tier 1 and 2 evaluation measurably improved the SRPE building response prediction, compared to the NDP and recorded displacements. Second, the deficiencies identified by the Tier 2 evaluation were consistent with the damage the building experienced.

These findings reinforce the central premise of this paper: information developed through targeted ASCE 41 evaluations can be used to meaningfully refine SP3 model inputs, improving probabilistic loss estimates while preserving the efficiency needed for portfolio-level decision making.

Conclusion

ASCE 41 and SP3 were developed to answer different questions, and both are powerful tools for evaluating existing buildings. Used together, however, they provide a broader understanding of seismic risk than either methodology can provide independently. ASCE 41 identifies structural deficiencies and potential retrofit strategies, while SP3 helps quantify what those deficiencies mean in terms of repair costs, functional recovery, and long-term seismic risk. The combination, with an engineer's judgement and clearly communicated recommendations, provides owners with information that is more directly applicable to capital planning and investment decisions.

The workflow presented in this paper demonstrates one practical approach to integrating these complementary tools. Across both municipal and private building portfolios, the engineering evaluation remained largely the same while the communication of the results adapted to the needs of each owner. In each case, the combination of structural evaluation and probabilistic loss assessment provided a more complete framework for comparing retrofit strategies than either approach alone.

Perhaps the most important outcome was not the development of new engineering analyses, but a different conversation with the owner. Rather than focusing solely on whether a building satisfied a prescribed performance objective, discussions

expanded to include recovery, operational priorities, anticipated ownership, available funding, and the relative benefit of different retrofit strategies. Those considerations often proved just as important as the engineering evaluation itself.

The workflow is not intended to replace engineering judgment or more rigorous project-specific analyses where they are warranted. Instead, it provides a practical framework for combining structural evaluation with quantified loss assessment to better support seismic investment decisions. As probabilistic performance assessment tools continue to evolve, integrating them with established engineering evaluation procedures offers an opportunity to provide owners with clearer, more meaningful information for managing seismic risk across their building portfolios.

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