A summary of performance-based seismic design of non-structural components with a focus on MEP-F systems

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Abstract

In this paper, we compare the performance-based design Solution and the Deemed-to-Satisfy Solution for seismic retrofitting of Mechanical, Electrical, Plumbing and Fire system (MEP-F) components in existing buildings. The comparison focuses on the application of these Solutions in areas with low seismic hazards, such as Australia. The performance-based design Solution is evaluated for its flexibility and detailed assessment approach, while the Deemed-to-Satisfy Solution is assessed for its simplicity and standardised procedures. Recommendations are provided on the suitability of each Solution for low-risk areas, highlighting their respective advantages and limitations.

Also, this paper compares the seismic bracing design for mechanical, electrical, and plumbing (MEP-F) systems in new versus existing buildings, focusing on assessing existing conditions, integration with structural elements, space constraints, structural limitations, minimizing disruption, code compliance, and cost considerations. It highlights the unique challenges and strategies required for retrofitting existing buildings while emphasizing the advantages of incorporating seismic bracing in new constructions.

Finally, this study outlines key seismic design recommendations for effectively integrating mechanical, electrical, and plumbing systems between existing and new buildings, addressing challenges such as compatibility, space constraints, and safety measures, with recommendations based on the authors' experiences.

Keywords: MEP-F (Mechanical, electrical, plumbing and Fire system), performance-based design (PBD), Seismic retrofit, existing building

1 Introduction

Mechanical, Electrical, Plumbing, Fire, and Medical Gas (MEP-F) systems are vital to the functionality and safety of buildings. During seismic events, these non-structural components are susceptible to damage, which can lead to operational disruptions, safety hazards, and significant financial losses. Designing MEP-F systems to withstand seismic forces is essential, specially in areas with low seismic hazard like Australia.

Two primary seismic design Solutions are commonly employed: the **Deemed-to-Satisfy Solution** and the **Performance-Based Design (PBD) Solution**. This paper compares these two Solutions, focusing on their application to MEP-F systems in low seismic hazard areas. It also examines the challenges and strategies involved in seismic bracing design for MEP-F systems in new versus existing buildings, emphasizing the importance of effective integration to enhance resilience and safety.

2 Overview design Solutions

The Deem-to-Satisfy relies on adherence to standardized building codes and prescriptive guidelines, offering simplicity and ease of implementation. In contrast, the PBD allows for tailored solutions by explicitly evaluating how MEP-F systems are expected to perform during seismic events, providing flexibility and detailed assessment.

The **Deem-to-Satisfy**, also known as the code-based design approach, involves designing buildings strictly according to the provisions specified in building codes and standards. This Solution assumes that adherence to these codes will result in acceptable seismic performance without the need for detailed performance evaluations. Designers follow predefined criteria, including seismic force levels, material specifications, load combinations, and detailing requirements outlined in codes such as the International Building Code (IBC), ASCE/SEI 7, and Australian Standards (e.g., AS 1170.4) for prescriptive designs.

The **PBD** is an advanced seismic design approach that focuses on achieving specific, quantifiable performance objectives for a building under various levels of seismic hazard. Unlike the prescriptive Deem-to-Satisfy, PBD allows for tailored design solutions by explicitly evaluating how a building is expected to perform during seismic events. This Solution involves detailed analyses, including nonlinear dynamic simulations, to assess and optimize the building's response to seismic demands, as outlined in standards such as ASCE/SEI 41 and FEMA P-58.

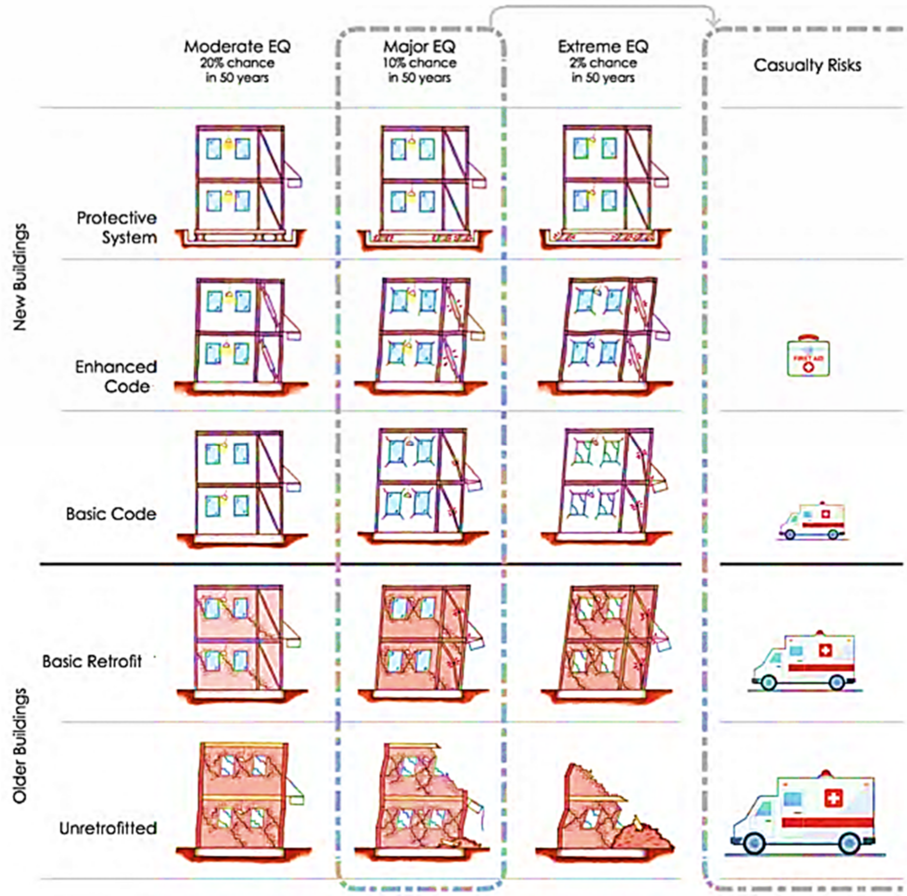

Figure 1. The range of earthquake consequences (From FEMA-P58)

Table 1. Comparison of Deem-to-Satisfy and Performance-Based Approaches:

Aspect	**Deem-to-Satisfy**	**Performance-Based Design Solution**
Approach	**Prescriptive, code-based** - Follows standardized codes - Limited flexibility	**Performance-oriented, analytical** Tailored design solutions High flexibility
Analysis Complexity	**Simplified analysis** - Linear elastic Solutions - Less complex, quicker	**Advanced analysis** - Nonlinear static and dynamic Solutions - More complex, specialized expertise required
Performance Evaluation	**Assumed acceptable performance** - Does not explicitly evaluate damage, losses, or downtime	**Explicitly evaluates performance** - Controls damage, casualties, repair time, and losses - Aims for enhanced resilience
Time and Cost	**Shorter design time** - Lower initial design costs - Potentially higher long-term costs due to unassessed risks	**Longer design time** - Higher initial design costs - Optimized construction and reduced lifecycle expenses
Applicability	**Suitable for standard buildings** - Common in typical projects - Not ideal for unique performance needs	**Ideal for complex or critical structures** - Preferred for high-importance or innovative projects - Addresses specific performance objectives
Advantages & Limitations	**Advantages:** - Simple, quick, cost-effective initially - Clear guidelines, easy compliance **Limitations:** - Less flexible, may not suit unique conditions - Potential for higher long-term costs	**Advantages:** - Customizable, thorough - Enhances resilience, potential long-term savings **Limitations:** - Time-consuming, higher upfront costs - Requires specialized expertise, complex approvals

Both the Deem-to-Satisfy and the PBD offer valuable approaches to seismic design. The Deem-to-Satisfy provides a straightforward and efficient means of ensuring compliance with building codes, making it well-suited for standard building projects. The PBD offers flexibility and detailed assessment, enabling customized solutions that can meet specific performance objectives.

In areas with low seismic hazard like Australia, the Deem-to-Satisfy is generally sufficient for most applications due to its practicality and ease of implementation. However, for certain projects such as critical facilities or buildings with unique requirements the PBD may be appropriate to achieve desired performance outcomes.

By carefully considering the specific needs and objectives of each project, designers and stakeholders can choose the seismic design Solution that best balances safety, cost, and performance, ensuring buildings are appropriately equipped to withstand seismic events.

3 Comparison of Seismic design Solutions for MEP-F Systems

3.1 *Application in Low Seismic Hazard Areas*

a. Adopt the Deem-to-Satisfy for Standard MEP-F Systems:

In low seismic hazard areas, the risk to MEP-F systems is relatively low, and the Deem-to-Satisfy provides a practical balance between safety and cost, making it suitable for buildings where MEP-F system functionality is not critical post-earthquake.

b. Consider PBD for Critical Facilities:

For hospitals, emergency services, or facilities where MEP-F systems are essential for life safety and immediate post-earthquake operations, PBD ensures that these critical systems remain operational or can be quickly restored.

c. Cost-Benefit Analysis:

Evaluate the importance of MEP-F systems against the seismic risk and project budget to determine if the enhanced resilience from PBD justifies the additional investment.

3.2 *Decision-Making Criteria for Selecting the Appropriate Approach*

When choosing between the Deem-to-Satisfy and the PBD for seismic design of Mechanical, Electrical, Plumbing, Fire, and Medical Gas (MEP-F) systems in low seismic hazard areas, it's important to consider several key factors. This decision should align with the project's specific needs, risks, objectives, and resource constraints. Below is a summarized guide to assist in selecting the most appropriate approach:

a. Criticality of MEP-F Systems

For standard buildings where MEP-F systems are not essential for immediate post-earthquake functionality, the Deem-to-Satisfy is generally sufficient, while for critical facilities like hospitals or emergency services, where uninterrupted operation is vital, PBD is advisable to ensure enhanced resilience and functionality during and after seismic events.

b. Seismic Risk Assessment

In low seismic hazard areas, where the likelihood of severe damage is lower, a cost-benefit analysis should evaluate whether the benefits of PBD justify the additional costs given the reduced risk.

c. Budget Considerations

For projects with a limited budget, the Deem-to-Satisfy offers a cost-effective solution with lower upfront expenses due to standardized designs and reduced engineering efforts, while if sufficient funds are available and long-term resilience is a priority, investing in PBD may be beneficial.

d. Regulatory Compliance

The Deem-to-Satisfy aligns with standard codes, facilitating simplified compliance and faster approval processes, whereas PBD may require extensive documentation, justification, and potentially peer reviews to satisfy regulatory authorities.

e. Project Timeline

For tight schedules, the Deem-to-Satisfy is quicker to implement due to its straightforward approach, while if the project allows for flexible timelines, PBD can be considered despite its more time-consuming nature.

f. Need for Customization and Innovation

For projects with conventional designs, the Deem-to-Satisfy is adequate, while those requiring customized solutions or innovative technologies should consider PBD for its flexibility.

g. Long-Term Performance Objectives

If the goal is to meet minimum safety standards, the Deem-to-Satisfy is appropriate, while for projects aiming to minimize damage, downtime, and ensure quick recovery, PBD offers a tailored approach to achieve these objectives.

To summarise,

Deem-to-Satisfy: Recommended for most MEP-F system designs in low seismic hazard areas due to its simplicity, cost-effectiveness, and sufficient compliance with safety standards.

PBD: Suitable for critical facilities or specialized projects where the enhanced performance of MEP-F systems is essential, and where the additional investment is justified by the need for higher resilience and functionality.

Selecting the appropriate seismic design Solution for MEP-F systems involves balancing factors such as system criticality, seismic risk, budget, regulatory requirements, project timelines, and performance goals. By carefully evaluating these criteria, stakeholders can make an informed decision that ensures safety, compliance, and optimal use of resources, aligning the seismic design approach with the specific needs and objectives of the project.

Consultation with experienced structural and seismic engineers is crucial to navigate the complexities of seismic design and to ensure that the chosen Solution adheres to both international and local codes and standards.

4 Seismic Bracing Design: New vs. Existing Buildings

Seismic bracing design for Mechanical, Electrical, Plumbing, Fire, and Medical Gas (MEP-F) systems varies significantly between new and existing buildings. In new constructions, seismic bracing can be seamlessly integrated into the design from the outset, allowing for optimal placement and coordination with structural elements. In contrast, existing buildings present unique challenges due to their established structures, requiring careful assessment and adaptation to incorporate seismic bracing without compromising the building's integrity or functionality.

4.1 Assessing Existing Conditions

Before implementing seismic bracing in existing buildings, a thorough assessment of the current conditions is essential. Conduct a structural evaluation to identify load-bearing elements and any previous modifications, inspect the condition and layout of existing MEP-F systems for potential impact points and vulnerabilities, and review historical building records to analyse construction Solutions and materials used.

4.2 Integration with Structural Elements

Effective seismic bracing requires integration with the building's structural components. Coordinate with structural engineers to ensure bracing designs align with structural capacities and do not overload existing elements, design connections to transfer seismic forces without damaging structural members, and address compatibility considerations between the existing structure and new bracing elements, including differences in materials or construction techniques.

4.3 Space Constraints and Structural Limitations

Existing buildings often have space and structural limitations that affect bracing design. Limited access in confined spaces may restrict the installation of standard bracing systems, while obstructions such as existing utilities, architectural features, or equipment may interfere with bracing locations, requiring custom or alternative bracing Solutions to accommodate these constraints.

4.4 Minimizing Disruption

To reduce impact on building operations and occupants during seismic bracing installation. Implement the project in phases to limit the areas affected at any given time, schedule installations during off-peak hours or planned downtime, and maintain clear communication with stakeholders regarding schedules and potential disruptions.

4.5 Code Compliance and Cost Considerations

Ensuring compliance with seismic codes while managing costs is crucial. Conduct a regulatory review to identify applicable codes and standards for seismic bracing in existing buildings, perform a cost-benefit analysis to weigh the benefits of bracing improvements against associated costs, and apply value engineering to explore cost-effective design alternatives that meet code requirements without excessive expenditure.

5. Challenges and Strategies in Retrofitting MEP-F Systems

Retrofitting Mechanical, Electrical, Plumbing, Fire, and Medical Gas (MEP-F) systems for seismic resilience involves unique challenges. Existing buildings may not have been designed with modern seismic standards, and integrating new seismic measures requires careful planning and execution.

5.1 Retrofitting of Existing MEP-F System

Some challenges may include Limited access and space constraints in existing structures may make it difficult to install seismic bracing without interfering with other building components. Ensuring compatibility with older MEP-F systems can be challenging due to outdated materials or designs, and retrofitting may disrupt building operations, especially in critical facilities like hospitals. Upgrading to meet current seismic codes may require significant and costly alterations, and the existing structural elements may not support additional loads imposed by new bracing systems.

The appropriate strategies could be a comprehensive assessment involves conducting thorough evaluations of existing MEP-F systems and structural components to identify vulnerabilities and constraints. Customized solutions should be developed to address specific challenges by utilizing flexible bracing systems or innovative technologies suited for limited spaces. Phased implementation is essential, scheduling retrofitting activities in stages to minimize disruptions, particularly by working during off-peak hours or planned downtimes. Collaboration with structural engineers is crucial to ensure that new bracing integrates seamlessly with the building's framework. A cost-benefit analysis should be conducted to evaluate the potential benefits of retrofitting against costs, allowing for the prioritization of critical areas and effective resource allocation.

5.2 Seismic Bracing in New System

Potential difficulties might involve integrating seismic bracing into new MEP-F systems requires design coordination among architects, structural engineers, and MEP designers to prevent conflicts, ensuring compliance with seismic codes like ASCE/SEI 7-16 and IBC, addressing space planning within architectural constraints while maintaining functionality and aesthetics, and balancing the cost of advanced seismic protection with overall project budgets.

Effective approaches could include incorporating seismic considerations early in the design stages optimising system layouts and bracing requirements, while standardization of bracing components and installation Solutions streamlines construction and reduces costs; fostering collaboration across disciplines ensures efficient communication, value engineering identifies cost-effective solutions that meet performance objectives, and the use of advanced technologies like seismic isolation or energy dissipation devices enhances overall performance.

6. Design Considerations for Efficient and Safe Implementation

6.1 Compatibility and Integration

Compatibility and integration are essential aspects of seismic design for Mechanical, Electrical, Plumbing, and Fire (MEP) systems, ensuring that all components work harmoniously within a building's overall structure. To achieve this, seismic design must account for the interaction between various MEP systems and the structural framework to prevent conflicts or overloads during an earthquake. For example, coordinating the placement of bracing and supports across systems like HVAC, piping, electrical, and gas lines is crucial to prevent interference and ensure that each system functions effectively under seismic stress. A thorough risk assessment must be conducted to understand vulnerabilities and optimize system integration.

Table 2. Technical Recommendations for MEP Systems Integration

System	Technical Recommendation
General	Coordinate seismic design, perform risk assessment.
HVAC Systems	Anchor and brace units, install flexible duct connectors and vibration isolators, use seismic restraints.
Piping Systems	Install seismic bracing, use flexible couplings and expansion joints, ensure clearance.
Elevators and Escalators	Anchor machinery, install seismic switches, brace guide rails.
Electrical Systems	Anchor panels and equipment, use flexible conduits, install seismic shut-off devices.
Lighting Fixtures	Secure fixtures with seismic-rated clips or safety wires, ensure emergency lighting systems are properly mounted.
Emergency Power Systems	Anchor generators and transfer switches, use flexible fuel lines and electrical connections.
Plumbing Systems	Brace water and wastewater pipes, install flexible joints, use shock absorbers.
Gas Lines	Anchor gas lines, install seismic shut-off valves, use flexible connectors.
Fire Protection Systems	Install seismic bracing for sprinkler systems, use flexible couplings, anchor water tanks.

6.2. Space Constraints and Safety Measures

Space constraints pose significant challenges in the seismic design of Mechanical, Electrical, Plumbing, Fire, and Medical Gas (MEP-F) systems. Limited space can hinder the proper installation of seismic bracing and supports, potentially compromising the safety and functionality of these critical systems during an earthquake. Implementing effective safety measures within confined spaces requires careful planning and innovative strategies.

Table 3. Solutions for Space Constraints and Safety in Seismic Design of MEP-F Systems

Challenges	Strategies
Tight or congested areas restrict placement of seismic bracing.	Collaborate with project stakeholders to identify space constraints early.

Difficult access for installation and maintenance.	Customized bracing solutions involve designing systems tailored to limited spaces, using modular components for easier installation in confined areas, providing access panels for maintenance and inspections, and conducting safety training to ensure personnel can work safely in confined spaces.
Overcrowding and conflicts with other utilities.	Re-route or consolidate MEP-F systems to reduce congestion.
Increased risk of damage during seismic events.	Flexible bracing materials involve using adaptable bracing that can navigate around obstacles and coexist seamlessly with other systems.
Ensuring designs meet codes within spatial limitations.	Ensure compliance with relevant standards like **AS 1170.4**
Need for space-efficient seismic devices.	Innovative technologies involve implementing space-saving seismic mitigation devices, such as vibration isolators, while regular updates ensure that designs and safety protocols remain current with regulations.

7. Conclusion

7.1 Selecting the appropriate seismic design Solution for MEP-F systems is crucial for ensuring safety, functionality, and resilience during seismic events. In low seismic hazard areas like Australia, the Deem-to-Satisfy is generally adequate for standard buildings due to its simplicity and cost-effectiveness. However, for critical facilities where uninterrupted operation is essential, the PBD offers significant advantages by providing customized solutions that enhance resilience and ensure rapid recovery.

7.2 The **cost-benefit trade-off** between these Solutions must be carefully considered, particularly in low-risk areas where the immediate need for advanced performance may not justify the higher upfront costs of performance-based solutions. However, for critical infrastructure, the potential long-term benefits of enhanced resilience and minimized downtime could outweigh the initial expense.

7.3 In addition, the **regulatory frameworks** governing seismic design, along with the involvement of relevant stakeholders, play a critical role in the decision-making process. Compliance with both local and international standards, along with active collaboration between structural engineers, project managers, and regulatory bodies, ensures that the chosen Solution meets both safety and legal requirements while considering project-specific needs.

7.4 When retrofitting existing buildings, **space constraints and integration challenges** become significant factors. Unlike new buildings where seismic bracing can be seamlessly incorporated, existing structures often require tailored solutions to address limited space and interference with other systems. This makes the PBD particularly valuable for retrofitting projects, as it allows for greater flexibility and optimization based on existing conditions.

7.5 By thoroughly evaluating project-specific factors and engaging with experts, stakeholders can make informed decisions that balance safety, cost, and performance objectives. Effective integration of seismic bracing in both new and existing buildings further strengthens the protection of MEP-F systems. Ultimately, aligning the seismic design approach with the specific needs and goals of each project ensures that buildings are better equipped to withstand seismic events, safeguarding occupants and maintaining essential services.

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