INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)

www.ijprems.com
editor@ijprems.com

Vol. 03, Issue 03, March 2023, pp : 170-174

e-ISSN : 2583-1062

Impact Factor : 5.725

AN EVALUATION OF THE LIFE-CYCLE RESILIENCE AND SUSTAINABILITY OF REINFORCED CONCRETE STRUCTURES WITH THERMAL-MASS SHEAR WALLS

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ABSTRACT

Considering the significant economic, social, and environmental repercussions of earthquakes, there is a growing recognition of the need for an integrated framework for life-cycle seismic performance evaluation of buildings. This study proposes a comprehensive approach for assessing the seismic resistance and sustainability of reinforced concrete buildings across their entire life cycle. The earthquake's life-cycle costs and direct and indirect impacts are assessed in terms of asset loss, time loss, human loss based on the number of casualties and fatalities, environmental damage based on greenhouse gas emissions, and energy consumption. To quantify the life-cycle losses, the FEMA approach for intensity-based and time-based loss analysis, economic input-output life-cycle assessment, and whole-building energy analysis of Energy Plus are applied. The framework is used for commercial reinforced concrete structures that have and do not have shear walls. The results reveal that RC shear walls may greatly increase resilience by lowering monetary loss and downtime while also improving interior air temperature variation and lowering energy consumption.

Keywords: Life cycle analysis, FEMA approach, loss estimation, Thermal-Mass Shear Walls, sustainability, analysis of Energy.

1. INTRODUCTION

In this study concerns about significant economic, social, and environmental losses caused by natural disasters, particularly earthquakes, hurricanes, and floods, have fueled a drive for comprehensive assessment and decision-making tools, approaches, and methodologies. Structure and infrastructure engineers may now quantify numerous engineering demand parameters (EDP) of the desired system and display a meaningful and complete description of its performance under high dangers, thanks to recent advancements in loss estimating methodologies. The life-cycle cost of the system's embodied and operational energy may also be assessed using process-based or economic-based life-cycle assessment (LCA) approaches and whole-building energy simulation tools. Yet, as evaluation techniques advance, the necessity for comprehensive assessment approaches that incorporate resilience, sustainability, and operational energy consumption data into a single holistic framework becomes more apparent. Buildings are the largest energy consumers, accounting for about 50% of total energy consumption in the United States (Horvath 2004). Around 30% of it is embodied energy from extraction, processing, and transportation. To quantify embodied energy in terms of CO_2 equivalent or other environmental measurements, process-based and economic input-output LCA methodologies are applied. Buildings need a significant amount of operational energy to condition the inside environment (heating, cooling, ventilation), power equipment, and so on. Because of their varying thermal characteristics, structural and non-structural components influence energy usage (e.g., thermal mass). The life-cycle cost of a structure is heavily influenced by choices made during the design process. For example, the mechanical/thermal characteristics of concrete, as well as the size and position of reinforced concrete (RC) shear walls on the plan, determine the transitional and rotational stiffness of the whole structure, as well as the building's elastic and nonlinear plastic performance. Surprisingly, the three parameters have a significant effect on heat/energy loss through the shear wall (with high thermal mass) as well as the total energy needed for heating and cooling the structure. The high thermal mass of RC shear walls amplifies this effect. The capacity of a structure or its components to store thermal energy is referred to as thermal mass. It has a discernible impact on the amount of energy used for cooling and heating, as well as occupant comfort. Thermal mass used well as an energy-efficiency strategy may result in an eco-friendly and sustainable design. The cost-effectiveness of this strategy will become clearer after the influence of building components with high thermal mass on resilience is examined. This research proposes a complete approach for assessing the life-cycle seismic resilience and sustainability of reinforced concrete buildings while taking thermal mass into account. To quantify the life-cycle asset loss, time loss, number of casualties and fatalities, as well as embodied and operational energy, the FEMA P-58 method for intensity-based and time-based resilience assessment, the Carnegie Mellon University method for economic input-output life-cycle assessment, and whole-building operational energy analysis performed in Energy Plus are used. The framework is being used for a collection of reinforced concrete (RC) commercial buildings in Los Angeles, California. This study's probabilistic life-cycle assessment framework attempts to enable comprehensive post-evaluation cost-benefit decision-making. Figure 1 shown the stepwise flowchart of Resilience, Sustainability, and Energy Analysis (RSEA).

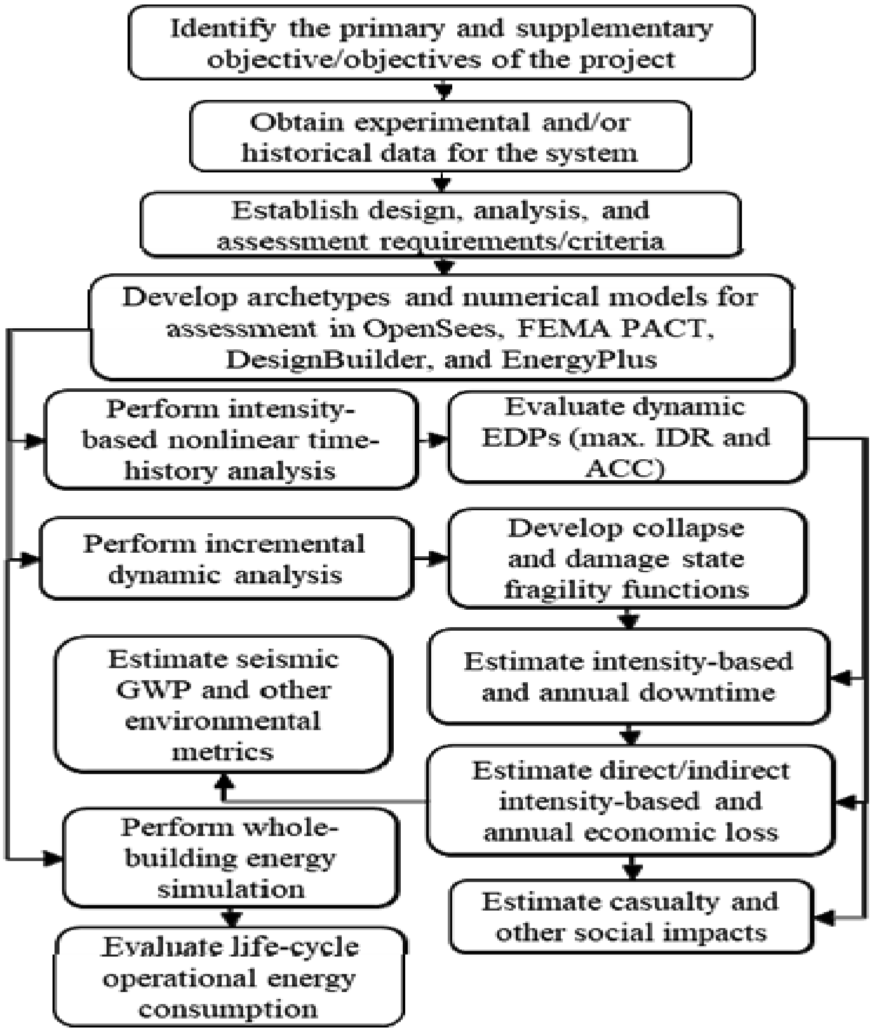

Figure 1: Stepwise flowchart of Resilience, Sustainability, and Energy Analysis (RSEA)

2. METHODOLOGY

The EIO LCA approach is used to measure sustainability parameters. The original cost of the structure and the loss due to earthquakes are used to calculate the life-cycle environmental effect of construction and maintenance operations. Table 2 illustrates the environmental effect of RC building construction and seismic repair/replacement throughout their entire life cycle. In Table 1, GWP refers for Global Warming Potential, while CO2 is for Carbon Dioxide. The terms fossil and CO2 Process refer to CO2 emissions into the atmosphere from fossil fuel combustion sources and sources other than fossil fuel combustion, respectively. Among the archetypes, 2SW has a substantially lower overall GWP than the other two. The frame building (RCF) has the greatest environmental impact due to earthquake since the amount of damage to RCF is greater than to others.

- **Analysis Life-cycle environmental impacts**

Table 1: Life-cycle environmental impacts

Metric	Greenhouse Gases			Water Withdrawal
	Total GWP	CO_2 Fossil	CO_2 Process	
Unit	ton CO_2e	ton CO_2e	ton CO_2e	kGal
Initial Construction				
4-story in	2,720	2,240	284	23,200

LA				
Annual Seismic Environmental Consequence				
2SW	17.4	14.4	1.59	162
1SW	27.8	23	2.55	259
RCF	76.5	63.1	7.01	713

- **Analysis to annual operational energy consumptions, water consumptions, equivalent CO2 emissions and their corresponding costs**

Table 2 summarizes the yearly operating energy and water consumptions, comparable CO2 emissions, and associated expenditures. The yearly energy consumption for all buildings with base glazing and high-performance glazing is around 150 kWh/m2 and 130 kWh/m2, respectively, which is consistent with the expected values of. Therefore, the yearly energy expenses of the same glazing type are comparable see Table 2. Lower glass areas in shear wall structures decrease HVAC energy use while increasing lighting demand because shear walls block some daylighting, as seen in Figure 2. Moreover, the price difference between electricity and natural gas mitigates the energy cost differential for the examined structures since RC frame buildings normally demand more energy for heating. As shown in Table 2, the adoption of high-performance glazing decreases the energy consumption of all building layouts. This difference is related to the energy savings in the HVAC system's operation. As compared to buildings with BG, HVAC reduces energy consumption by 25.6%, 21.3%, and 20.9% for 2SW, 1SW, and RCF, respectively.

Table 2: Annual operational energy consumption, water consumption, equivalent CO2 emission and costs for studied arche types with different glazing

Model	Energy/Cost (MWh/k$)	Water (kGal/k$)	CO_2e (ton/k$)
2SW-BG	527.0/87.7	387.3/2.9	349.5/7.0
1SW-BG	530.8/88.7	387.3/2.9	353.3/7.1
RCF-BG	540.3/88.6	387.3/2.9	308.2/6.2
2SW-HG	480.6/81.1	387.3/2.9	322.8/6.5
1SW-HG	482.9/81.7	387.3/2.9	325.3/6.5
RCF-HG	474.5/79.6	387.3/2.9	316.9/6.3

3. RESULTS & DISCUSSION

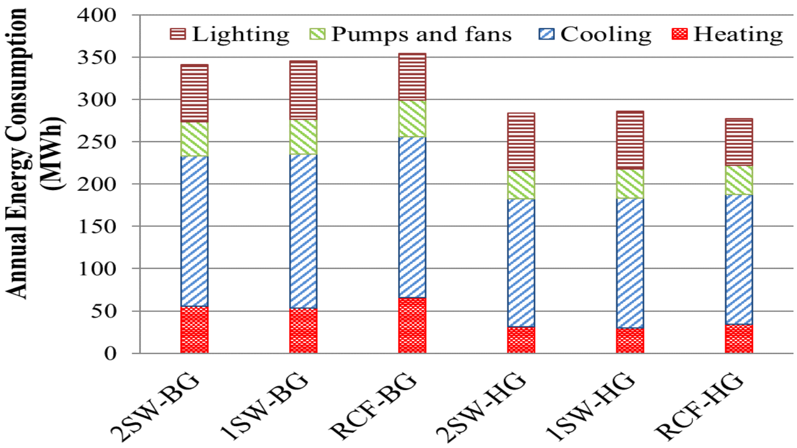

Figure 2: HVAC and lighting energy consumptions of RC buildings with different window glazing

The adaptive comfort model based on ASHRAE Standard 55-2010 was used to determine the thermal comfort of the occupancy. When the temperature is between 10 ^{0}C and 35 ^{0}C, the model assumes that the comfort temperature is a function of the monthly mean outside air dry-bulb temperature, and LA meets this condition. It establishes two acceptance criteria, 80% and 90%, to signify whether or not the interior air temperature falls within the prescribed parameters. The RCF-BG, 1SW-BG, and 2SW-BG prototype buildings are used to demonstrate the possible influence of shear walls on thermal comfort. Figure 3 illustrates the amount of time when the ASHRAE55 80% acceptable level is not fulfilled in hours. It demonstrates that the use of shear walls may significantly minimize the amount of time

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when the interior comfort temperature is not attained. Building 2SW-BG took roughly 30% less time than constructing RCF-BG. This is consistent with studies that show thermal mass walls help lessen interior air temperature fluctuation in buildings.

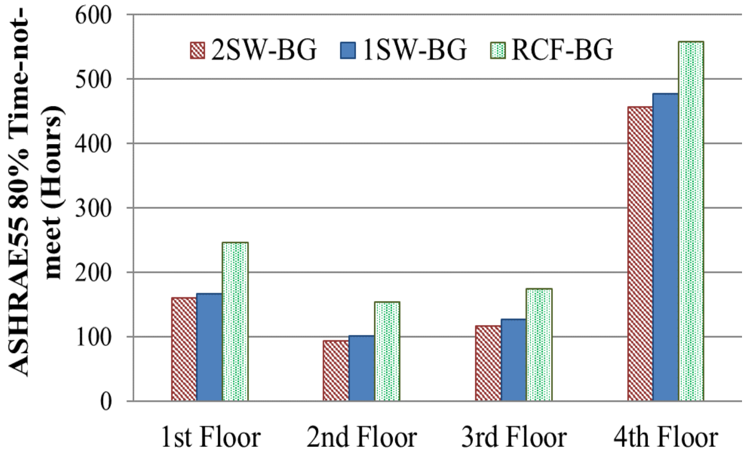

Figure 3: Time not meet ASHRAE55 adaptive thermal comfort model 80% limits requirements for buildings with base glazing

4. CONCLUSIONS

To quantify numerous economic, social, and environmental parameters, a framework for building structure resilience, sustainability, and energy evaluation is provided. This comprehensive methodology serves as the foundation for a risk-informed multi-criteria life-cycle decision analysis of structural-architectural systems. Utilizing RC shear walls may dramatically increase building performance. It considerably minimises the collapse inter-story drift (around 800% on average) and hence reduces monetary loss and downtime. In addition to these performance advantages, shear walls may effectively minimise the in-door air temperature fluctuation, as shown by ASHRAE55 estimates that a reduction of 30% of the time does not satisfy the 80% thermal comfort standard. Stiff shear wall frames, on the other hand, will suffer enormous absolute maximum spectral acceleration, affecting non-structural components prone to extreme acceleration, such as suspended ceilings. This may result in more casualties in shear wall RC structures than in frame RC buildings. For example, the RC frame has an annualised number of injuries of 0.0132, but shear wall RC archetypes have an annualised rate of injuries of 0.0365. Moreover, since shear walls have a high thermal mass, base glazing reduces yearly HVAC energy use.

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