A RAPID VISUAL SCREENING (RVS) SCORE DEVELOPMENT FRAMEWORK FOR STEEL BUILDINGS IN DHAKA CITY

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ABSTRACT

Bangladesh is situated at the junction of the Indian, Eurasian, and Burma tectonic plates, placing the country in a high seismic hazard zone of South Asia. With the return period for major earthquakes (M 7-8) already exceeded, the potential for a massive event remains high, while frequent mild-to-moderate tremors highlight the vulnerability of the built environment. In Dhaka alone, about 325,000 buildings exist, making it unrealistic to perform detailed seismic evaluations for the entire stock within a reasonable timeframe. For emergency preparedness and disaster risk management, it is essential to rapidly identify buildings with higher seismic vulnerability, particularly those intended to serve as post-earthquake shelters. The Rapid Visual Screening (RVS) procedure outlined in FEMA P-154 offers a practical solution by enabling quick assessment of large building inventories through sidewalk surveys without entering buildings. However, its default scoring system is calibrated for U.S. building typologies and soil characteristics, limiting its direct applicability in Bangladesh. This study develops RVS scores for mid-rise steel moment-resisting buildings in Dhaka, considering BNBC 2020 soil classes. Due to differences from ASCE site classes, ground motion suites for site classes SB and SC were selected from the PEER Ground Motion Database using BNBC 2020-defined shear-wave velocities for Seismic Zone 2, ensuring that each suite's average acceleration response spectrum matched the corresponding soil design spectrum, following FEMA P-58 principles. A representative six-story, four-bay steel frame and a soft-story irregular variant were modeled. The capacity spectrum method and Incremental Dynamic Analysis (IDA; multiple nonlinear time-history analyses with increasing seismic intensities) were used to obtain performance points and fragility curves, from which basic RVS scores and score modifiers were derived probabilistically. The basic RVS score was 3.3 for Site Class SB and 3.0 for Site Class SC. The latter aligns with the FEMA P-154 reference basic score of 2.7 for moderate seismicity regions in the U.S. The soft-story modifier for Site Class SC (−1.65) was comparable to the reference value (−1.2), indicating consistent identification of soft-story vulnerability. By applying these scores, seismic vulnerability of steel buildings in Dhaka can be rapidly assessed, identifying safe buildings and prioritizing retrofitting of critical assets.

Keywords: *RVS score, Seismic vulnerability assessment, Incremental Dynamic Analysis (IDA), Seismic fragility curves, FEMA P-154*

1. INTRODUCTION

Seismic vulnerability assessment of buildings is conventionally performed in three stages: rapid visual assessment (RVA), preliminary engineering assessment (PEA), and detailed engineering assessment (DEA). RVA evaluates structural and non-structural components on-site to assign seismic damage grades (American Society of Civil Engineers, 2017). It requires several hours per building for decision-making regarding further evaluation, making citywide application impractical in a megacity like Dhaka. Rapid identification of seismically safe buildings - particularly critical facilities such as hospitals, fire stations, and schools that support emergency response - is essential for guiding public awareness and retrofitting decisions. Therefore, a fast and reliable seismic vulnerability assessment framework is fundamental for effective seismic disaster risk management in large urban areas.

The FEMA P-154 (2015a) rapid visual screening (RVS) methodology provides a practical basis for quick and cost-effective seismic safety assessments for a variety of building typologies (e.g., steel, reinforced concrete, and masonry) and lateral-load resisting systems (e.g., moment-resisting frames, shear walls, and reinforced or unreinforced masonry). It assigns basic numeric scores to buildings according to their type and regional seismicity, which are subsequently modified through the addition or subtraction of score modifiers to account for factors such as vertical and plan irregularities, construction year, seismic detailing, and local soil type. The resulting final score is compared with a minimum threshold for each FEMA building type to determine seismic safety. The RVS procedure can be conducted as a sidewalk survey around buildings, generally requiring 15 to 30 minutes inspection time for each building. Therefore, it serves as one of the most efficient approaches for large-scale seismic safety evaluation.

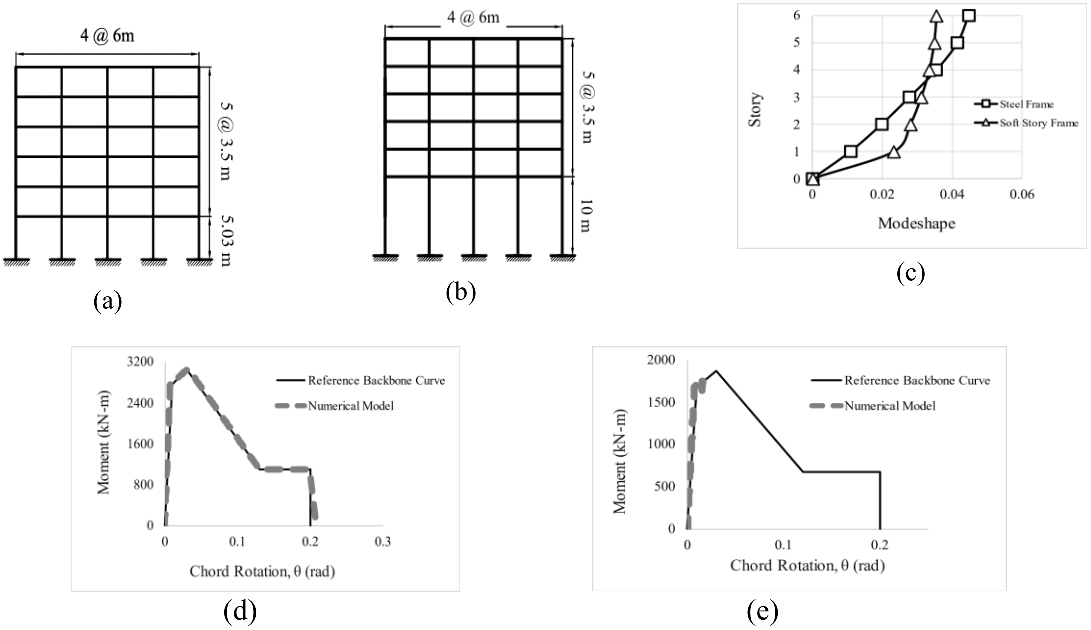
However, the FEMA P-154 scoring system is calibrated for U.S. building typologies, seismicity, and soil conditions. The site classifications defined in ASCE/SEI 7-10 differ from those in the Bangladesh National Building Code 2020. Consequently, applying the default FEMA P-154 scores directly to buildings in Dhaka may produce inaccurate results. To enable the application of rapid visual screening in Bangladesh, it is necessary to develop RVS scores specific to the soil site classes and seismic hazard zones defined in BNBC 2020, as well as to standardized local building types.

Jain et al. (2010) developed a damage data-based rapid visual screening (RVS) method for RC frame buildings in India using post-earthquake evidence from the 2001 Bhuj earthquake, highlighting the importance of region and building typology specific RVS frameworks. Ningthoujam and Nanda (2018) developed a rapid visual screening procedure for Indian buildings using statistical regression on post-earthquake damage data, identifying key building parameters that influence vulnerability. Purushothama et al. (2023) evaluated the rapid visual screening method for masonry-infilled RC buildings in Algeria by comparing its scores with results from static pushover and incremental dynamic analyses, showing that RVS scores reliably captures the relative vulnerability trends. FEMA P-155 (2015b) provides the technical basis for the development of the RVS scoring system used in FEMA P-154 (2015a). This paper proposes a FEMA P-155 based implementation framework to estimate RVS scores for steel buildings in Dhaka City, which can be extended to other commonly used building typologies in Bangladesh.

2. METHODOLOGY

2.1 Finite Element Modeling and Analytical Verification of the Representative Steel Frame

A two-dimensional (2D) numerical model of a six-story, four-bay steel frame was developed using the finite element software OpenSees. To represent vertical irregularity, a soft story frame was modeled with higher ground story heights. The geometries are illustrated in Figure 1(a) and 1(b). The steel sections for columns and beams were selected as W14×193 for story level 1-3 and W24×233 for story level 4-6, and W24×94 and W24×146 for beams in story level 1-3 and 4-6 respectively. The steel material properties include a yield strength of 50 ksi, modulus of elasticity of 29,000 ksi, and a strain hardening ratio of 0.01. Columns were modeled using the Steel02 material model. Beams were modeled using elastic steel material. Boundary conditions were assigned as fixed supports at the base nodes, and beam-column joints were constrained in translation and released in rotation to capture the nonlinear moment-rotation behavior of the plastic hinges. Gravity loads were applied assuming a 3 m tributary width on each side of the frame, considering dead load (40 psf), floor finish (25 psf), partition wall load (80 psf), and a live load of 100 psf as per BNBC (2020). For seismic load combinations, 50% of the live load was considered. Geometric nonlinearity was modeled using P-Δ transformation. Material nonlinearity was represented through plastic hinges at both ends of each beam using the modified Ibarra-Medina-Krawinkler (IMK) deterioration model. The moment-rotation response from the pushover analysis shows close agreement with the corresponding backbone curves of Lignos and Krawinkler (2011) in Figure 1(d) and 1(e), thereby validating the nonlinear modeling approach. The first and second mode time periods obtained from the modal analysis are 1.27 s and 0.43 s for the regular steel frame, and 2.12 s and 0.55 s for the soft-story frame. The first-mode shapes shown in Figure 1(c) illustrate the primary lateral sway direction of the frames.



(a) (b) (c)

(d) (e)

Figure 1: (a) Steel frame, (b) Soft story steel frame, (c) First mode shape of the frames; Pushover moment-rotation response at exterior joints of (d) W 24X146 beam between 1st and 2nd story, (e) W 24X94 beam between 4th and 5th story

2.2 Determination of Performance Point

The performance point is obtained from the Capacity Spectrum Method (CSM), where the demand curve represents the expected seismic demand at the site and the capacity curve represents the structure's ability to resist that demand. Their intersection on the capacity-demand plot defines the performance point of the structure, as shown in Figures 3(a), 3(b), and 3(c). The capacity curve is derived from a nonlinear static pushover analysis, in which the structure is subjected to monotonically increasing lateral load until a target roof displacement is achieved. The resulting pushover curve - base shear (V) versus roof displacement $\left(\Delta_{roof}\right)$ - is converted to capacity curve (Spectral acceleration, S_a Vs. Spectral displacement, S_d) using equation (1) and equation (2).

$$S_d = \frac{\Delta_{roof}}{\Gamma * \phi_{roof}} \qquad (1)$$

$$S_a\,(g) = \frac{V}{W\alpha_1} \tag{2}$$

Where, ϕ_{roof} is the first mode shape at roof node, Γ is the modal participation factor; W is the seismic weight of the structure, α_1 is the fraction of building weight effective in pushover mode.

Demand curve is obtained from site-specific design response spectrum. C_s Vs. T curve for soil site class SC and SB for 5% damping is taken from BNBC (2020), and converted to S_a Vs. T by using equation (3). The S_a Vs. S_d is derived using equation (4).

$$S_a\,(g) = \frac{2ZI}{3R}C_s \tag{3}$$

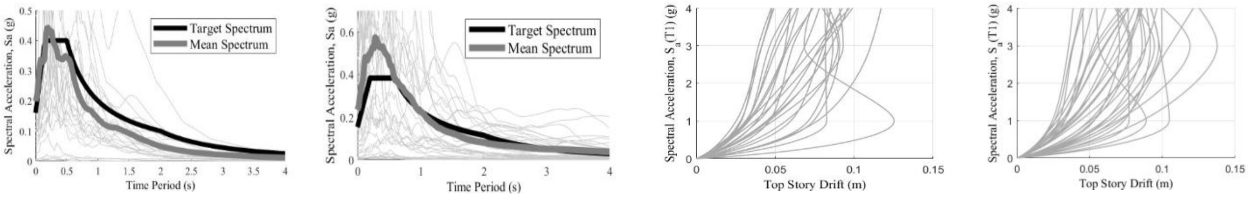
$$S_d = \frac{S_a T^2}{4\pi^2} \tag{4}$$

Where, Z = seismic zone coefficient = 0.2 for seismic zone 2; both the importance factor (I) and response reduction factor (R) are assumed unity according to BNBC (2020) to obtain "design acceleration response spectrum" for inelastic analysis; T = first mode time period of the structure.

2.3 Determination of Median Spectral Displacement

2.3.1 Selection of Ground Motion

Site-specific ground motions are essential for accurately evaluating structural response under local seismic hazards. In this study, 24 records representing site class SB (shear wave velocity 360-800 m/s) and 31 records for site class SC (180-360 m/s) were selected from the PEER Ground Motion Database (Pacific Earthquake Engineering Research Center, n.d.), ensuring the mean response spectra closely match the BNBC (2020) design spectra for seismic zone 2. This selection follows FEMA P-58 guidelines (Federal Emergency Management Agency, 2018). Figure 2(a) and 2(b) show the spectral matching.



(a) (b) (c) (d)

Figure 2: Spectral matching for ground motions - (a) Site class SB, (b) Site class SC; IDA curves of steel frame obtained for ground motions at site class - (c) SB, (d) SC

2.3.2 Incremental Dynamic Analysis (IDA)

Incremental Dynamic Analysis (IDA) involves performing nonlinear dynamic analyses using a suite of ground motion records, each scaled to increasing intensity levels to drive the structure from elasticity to instability (Vamvatsikos & Cornell, 2004). IDA curves are plots of a ground motion intensity measure (IM), such as peak ground acceleration (PGA) or 5% damped first-mode spectral acceleration (S_a (T_1, 5%)) against a structural damage measure (DM), such as roof drift or inter-story drift ratio. In this study, IDA was performed for the steel frame using 24 and 31 ground motion records as shown in Figure 2(c) and 2(d) respectively, and for the soft-story frame using 22 records.

2.3.3 Fragility Assessment

A fragility curve represents the probability that a structure will reach or exceed a specified damage state for a given earthquake intensity, expressed as a lognormal cumulative distribution function (CDF) of the intensity measure. For RVS score development, only the complete damage state is considered, indicating risk of collapse. The maximum drift for complete damage in a mid-rise steel moment-resisting frame (S1M) is 0.0533m (FEMA, 2012). This damage state is mapped onto IDA curves to obtain the corresponding S_a values, which is then converted to S_d using equation (4). The probability of complete damage is computed using equations (5), (6), and (7).

$$S_{d,\ median} = e^{\frac{\sum_{i=1}^{N} ln\,(S_d)_i}{N}} \tag{5}$$

$$\beta = \sqrt{\frac{\sum_{i-1}^{N} \left[ln(S_d)_i - ln(S_{d,median})\right]^2}{N-1}} \tag{6}$$

$$P\,[Complete\ Damage] = P\,[Complete\ Damage \mid S_d\,] = \phi\left(\frac{ln(S_d)_i\ -\ ln\,(S_{d,median})}{\beta}\right) \tag{7}$$

Where, N = Number of ground motion records used for IDA; β = Logarithmic standard deviation of the fragility function, representing the variability in the structural capacity due to record-to-record differences in ground motion intensity; $P[Complete\ Damage]$ = Fragility based probability of complete damage.

Plotting the $P[Complete\ Damage]$ Vs. S_d generates the complete damage fragility curve. The S_d value corresponding to a 50% probability of complete damage on this curve represents the median spectral displacement ($S_{d,\ Complete\ Damage}$), as shown in Figure 3(d), 3(e), and 3(f).

2.4 Calculation of RVS Score

In the RVS scoring framework, probability of complete damage, $P_{RVS}\,[Complete\ Damage]$ represents the likelihood that a structure's performance point (Sd_{pp}) will be exceeded by the spectral displacement corresponding to 50% probability of complete damage (median spectral displacement, $S_{d,Complete\ Damage}$) during an earthquake. It is modeled as a lognormal cumulative distribution function (CDF), as expressed in equation (8). The collapse factor for mid-rise steel moment resisting frame type building is 5% (FEMA, 2012). Probability of the structural collapse is estimated using equation (9).

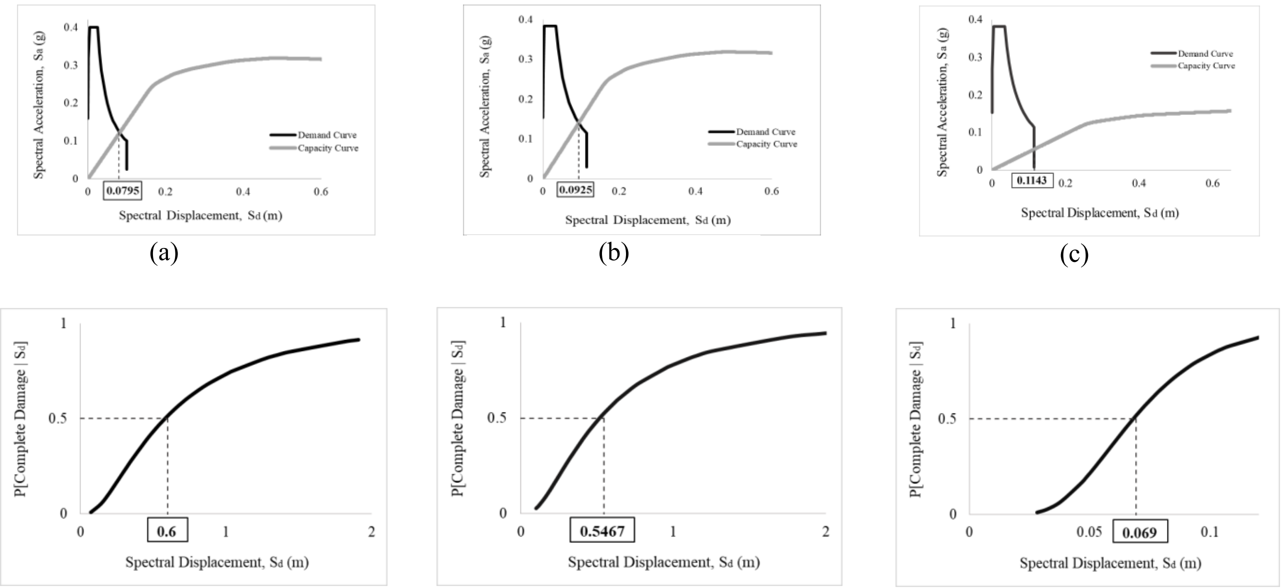
$$\begin{aligned} P_{RVS}\,[Complete\ Damage] &= P_{RVS}\,[Complete\ Damage \mid Sd_{pp}] \\ &= \phi\left(\frac{ln\,(S_{dpp}) -\ ln\,(S_{d,\ Complete\ Damage})}{\beta_{Complete\ Damage}}\right) \end{aligned} \tag{8}$$

$$P\,[Collapse] = P_{RVS}[Complete\ Damage]\ \text{x}\ Collapse\ Factor \tag{9}$$

The basic RVS score is quantified as the negative natural logarithm of the probability of collapse using equation (10). The score modifier for a building with certain irregularities is obtained by subtracting the basic score of the irregular building frame from the basic score of the standard building frame.

$$S = -\ log_{10}\,P[Collapse] \tag{10}$$

3. RESULTS AND DISCUSSION



(a) (b) (c)

(d) (e) (f)

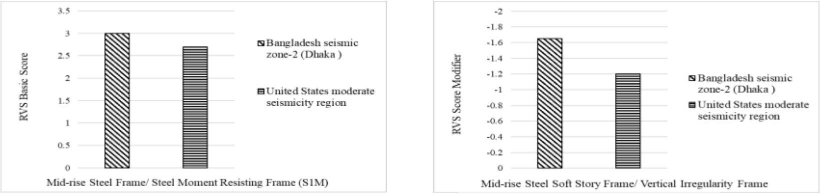
Figure 3: Performance point for steel frame at site class - (a) SB, (b) SC, (c) SC (soft story); Median spectral displacement for steel frame at site class - (d) SB, (e) SC, (f) SC (soft story)

The RVS scores for the representative steel building frames at site classes SB and SC, along with the score modifier for the soft-story steel frame at site class SC, are summarized in Table 1.

Table 1: Calculation of RVS score

	Steel Frame		Steel Soft Story Frame
	SB	**SC**	**SC**
Performance point, $S_{d_{pp}}$	0.0795	0.0925	0.1143
Median spectral displacement, $S_{d,\ CompleteDamage}$	0.6	0.5467	0.069
Lognormal standard deviation, $\beta_{Complete\ Damage}$	0.8708	0.8565	0.3930
Probability of complete damage, *P* [*Complete Damage*]	0.01014	0.019024	0.900497
Probability of collapse, *P*[*Collapse*]	0.000507	0.000951	0.045024
Basic score, *S*	3.3	3.0	1.35
Score modifier			-1.65

The higher basic score for Site Class SB relative to SC reflects the improved seismic performance of buildings on stiffer soils, as lower shear-wave velocity soils tend to amplify and prolong ground shaking. The negative soft-story score modifier indicates that vertical irregularity adversely affects structural response by causing uneven lateral force distribution. Dhaka lies in seismic zone 2, a moderate seismic risk region under BNBC (2020). FEMA P-154 (2015a) defines five seismicity levels and provides basic scores and irregularity modifiers calibrated for average of the soil classes C and D. Accordingly, the RVS scores for steel frames on Site Class SC in Dhaka are compared with FEMA P-154 building type S1M (mid-rise steel moment frame) scores for moderate seismicity in Figure 4. Site Class SB is excluded from this comparison.



(a) (b)

Figure 4: Cross-country comparison of RVS score for - (a) Regular steel frame, (b) Irregular steel frame

4. CONCLUSION

This study employed two-dimensional (2D) frame models for static and dynamic analyses to determine the basic score and vertical irregularity modifiers. Three-dimensional (3D) modeling is required to evaluate plan irregularity modifiers and to more accurately capture the torsional effects in overall structural response. The material properties and connection behavior assumed for the numerical models represent well-detailed steel construction, whereas many existing steel buildings of Dhaka may lack adequate seismic detailing. This assumption may lead to an underestimation of the actual seismic vulnerability reflected by the RVS score; however, it is consistent with the FEMA P-154 “Level 1” screening approach, which idealizes buildings as structural framing systems based only on exterior “sidewalk survey” observations. Detailed material and structural deficiencies are addressed in “Level 2” screening, which requires interior access and is beyond the scope of this study.

Although the developed RVS scores for steel frames show close agreement with FEMA P-154 reference scores, they have not been validated against post-earthquake damage data, expert-based screenings in Dhaka, or existing vulnerability studies. Therefore, the results of this study should be viewed as a methodological framework, and future research incorporating field observations and comparative validation is necessary to confirm the reliability and applicability of the proposed scores.

Building on the methodology proposed in this study for steel frames, the framework provides a foundation that could potentially be adapted to other building types - including reinforced concrete, masonry, and precast structures - with various lateral load-resisting systems and structural irregularities across multiple site classes (SB, SC, SD) and seismic zones of Bangladesh. The proposed RVS framework offers a scalable pathway to support national disaster preparedness by informing effective emergency planning and policy decisions, which are essential for sustainable urban growth and development.

DECLARATION OF USE OF AI

AI tools were used solely for editorial language refinement and did not contribute to the research design, methodology, or results. All scientific judgments, interpretations, and conclusions remain the responsibility of the authors.

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