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Disaster Assessment of Tall Buildings in Korea by K-Rapid Visual Screening System Focusing on Structural Safety

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Abstract: Multiple hazards, which threaten people's lives and property, are the main concern for engineers in preventing dangers to buildings. In particular, densely populated areas, such as capital cities and tall buildings, are exposed to higher risks owing to multiple hazards. To rapidly evaluate the disaster assessment of tall buildings, the Federal Emergency Management Agency (FEMA) in the U.S. proposed the integrated rapid visual screening system (IRVS). However, the IRVS system only considers U.S. conditions. Therefore, a Korean-oriented rapid visual screening system should be developed because the number of buildings over 200 m in Korea ranked fourth in the world with the highest density (500 people per square kilometer) among the top five countries based on the Council on Tall Buildings and Urban Habitat's (CTBUH) database. This study describes a Korea-rapid visual screening (K-RVS) system that focuses on the structural safety of tall buildings in Korea. The K-RVS system was modified based on the IRVS, considering the Korean design standard (KDS) and Korean conditions. With the weight value for each characteristic, the scores for each hazard and final scores combined from the scores by multi-hazard can be obtained to conduct a disaster assessment of tall buildings subjected to multiple hazards.

Keywords: disaster assessment; tall buildings; rapid visual screening system; K-RVS; IRVS

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1. Introduction

There are various hazards that threaten life and property. Recently, civil engineers tried to prevent damage in buildings subjected to multiple hazards and to prepare their resilience [1–3]. To evaluate the effects of hazards on buildings, the Department of Homeland Security (DHS) in the United States set out to develop a multi-hazard risk assessment system after the events of 11 September 2001 [4]. This system, also known as integrated rapid visual screening (IRVS), was based on the framework set forth in the design guides [5–7] and rapid visual screening (RVS) [8–10] for safety and mitigation of several hazards (earthquake, fire, winds, blast, etc.) by the Federal Emergency Management Agency (FEMA). IRVS is available for evaluating risk assessment under multiple hazards and provides opportunities for gathering building information data of not only public buildings but also private ones.

The risks posed by multiple hazards are maximized in densely populated areas, such as capital cities and tall buildings. In the case of Korea, the risks of multiple hazards are higher than those of developed countries because the number of buildings over 200 m currently ranks 4th in the world, with the highest density (500 people per square kilometer) among the top five countries based on the Council on Tall Buildings and Urban Habitat's (CTBUH) database [11]. The Korean government enacted the first high-rise building law for disaster management to prevent multiple hazards and reduce their occurrence. However, this law focused on the egress plan related to post-disaster. Therefore, design considerations to prevent disasters and reduce risks related to pre-disaster were barely considered; however, several studies on risk assessment for disaster prevention in Korea

have been conducted [12–15]. Lee and Kim proposed an improved direction for the design procedure considering architectural factors in building security control systems [12], and Kang et al. studied the vulnerability assessment of high-rise buildings in Korea via explosive terror risk investigations based on the RVS of FEMA [13]. Yu et al. evaluated the terror risk of tall buildings in Korea using the modified RVS and IRVS systems [14], and Lee and Yoon assessed the strong wind risk of tall buildings in Korea using IRVS [15]. Kang et al. classified architectural design elements of multiuse buildings considering terror risk by investigating the RVS system [16]. In addition, Kang et al. surveyed the perspectives of architectural design practitioners on the anti-terrorism design of multiuse buildings to suggest design guidelines [17]. Kim et al. systemized an integrated risk management strategy for high-rise buildings subjected to various disasters using the Korean Integrated Disaster Evaluation Simulator (K-IDES) [18], and also developed a K-IDES system with a risk assessment method and building simulations [19]. Disaster assessment guidelines for tall buildings in Korea using RVS according to Korean conditions have been proposed [20].

Asprone et al. [21] proposed a probabilistic model for multi-hazard risk related to limit state collapse for concrete structures under the post-earthquake blast. Explosions both inside and outside the structure were considered for the blast scenario. Various structural types were proposed as the further research target for this condition. Kameshwar and Padgett [22] described a parameterized fragility based multi-hazard risk assessment for highway bridges under earthquakes and hurricanes. In addition, hurricane wave and surge loading were additional risks for assessing the risk of the bridges. Gentile et al. [3] proposed the Indonesia school program to increase resilience to assess the seismic risk of concrete buildings and calculate Papathoma tsunami vulnerability. Koks et al. [23] presented the first global estimates for assessing multi-hazard risk for road and railway infrastructure assets with the global expected annual damage index. Dabbeek and Silva [24] proposed an exposure model for multi-hazard risk assessments of residential buildings in the Middle East. Kwag et al. [25] proposed a novel framework to find the governed hazards based on the performance-based design requirement under earthquake and wind loads. Wei et al. [26] proposed a quantitative multi-hazard risk assessment of buildings in the Jiuzhaigou Valley, one of the natural heritage sites in Western China, that is endangered by rockfalls and debris flows.

In this study, the K-RVS system was proposed by making IRVS dependent on Korean conditions and the Korean design standard (KDS) [27] to assess major disasters (earthquake, wind, fire, blast) for tall buildings, and its validation was obtained. Because the number of tall buildings in Korea ranks fourth in the world with the highest density among the top five countries, the Korean government enacted the first high-rise building law for disaster management. This law aims to prevent multiple hazards and reduce their occurrence. However, as numerous tall buildings were already built before enacting the law, a rapid assessment system for existing tall buildings under multi-hazards should be developed. Thus, the disaster assessment system (K-RVS) is a method that provides guidance and explanations on interpreting the severity of potential hazards over the identified risk assessment of tall buildings in Korea, focusing on structural safety.

2. Structure of the K-RVS System

2.1. General

K-rapid visual screening (K-RVS) is an assessment system for evaluating tall buildings with agile analysis via a review of the knowledge and available data on the buildings. It is a modified version of the IRVS, which was adapted for use in Korea with the goal of improving the evaluation procedure in Korean buildings, and enabling the proper assessment of buildings prone to earthquake, fire, wind, and blast risks. Furthermore, K-RVS contains pre-field data, consequences, threats, and vulnerability components similar to IRVS, as shown in Figure 1.

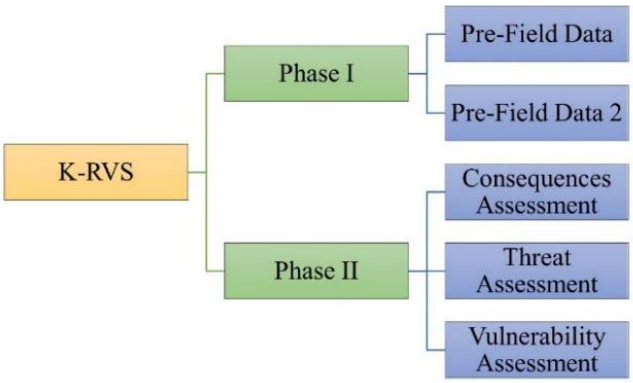


Figure 1. K-RVS components.

IRVS describes pre-field data such as relevant building identification information, threats and hazards, and datatypes that are not readily available in the field. However, this information contains some of the most important components with high weight values. In this phase, two categories were chosen to belong to pre-field data 1 and 2. Pre-field data 1 and 2 were compounded for three and thirteen characteristics, respectively, as presented in Table 1. Phase two has three categories: consequences, threats, and vulnerability. Consequences and threats were compounded for three characteristics each, and vulnerability was compounded for twenty-eight characteristics (Table 1).

Table 1. K-RVS of detailed components.

Phase I		Phase II		
Pre-Field 1	**Pre-Field 2**	**Consequences**	**Threat**	**Vulnerability**
Hazard	Number of Occupants Replacement Value Occupancy Use Target Density: Zone I	Locality/Density Type	Site Population Density	Nearby Structures Topography/Slopes Condition of Foundation Retaining Walls Potential of Soil Liquefaction Building Height Overhang Horizontal Irregularity
Structure Type	Target Density: Zone II Target Density: Zone III Target Potential: Building Target Potential: Sector Seismic Zone	Operational Redundancy	Visibility/Symbolic Value	Vertical Irregularity Number of Bays in the Short Direction Column Spacing Unbraced Column Height Publicly Accessible Column Transfer Girder Conditions Structural Enhancements and Weaknesses Number of Lateral Systems Short Columns or Walls Seismic Design/Retrofit
Resiliency Computations	Proximity to an Active Seismic Fault High Wind Speed Zone Typhoon Frequency in the Region Soil Type	Impact of Physical Loss	Overall Site Accessibility	Roof Span Topping Slabs Adjacent Building Separation Wall Type Windborne Debris Impact Protection Exterior Fireproof Walls Seismic Design Category Allowable Story Drift Surface Roughness Enclosure

To properly complete the assessment of a building, four steps are necessary; the gathering of pre-fields, consequence assessment, threat assessment, and vulnerability assessment (Figure 2). During the steps in the K-RVS system, the screener deals with six variables subjected to major scoring considerations.

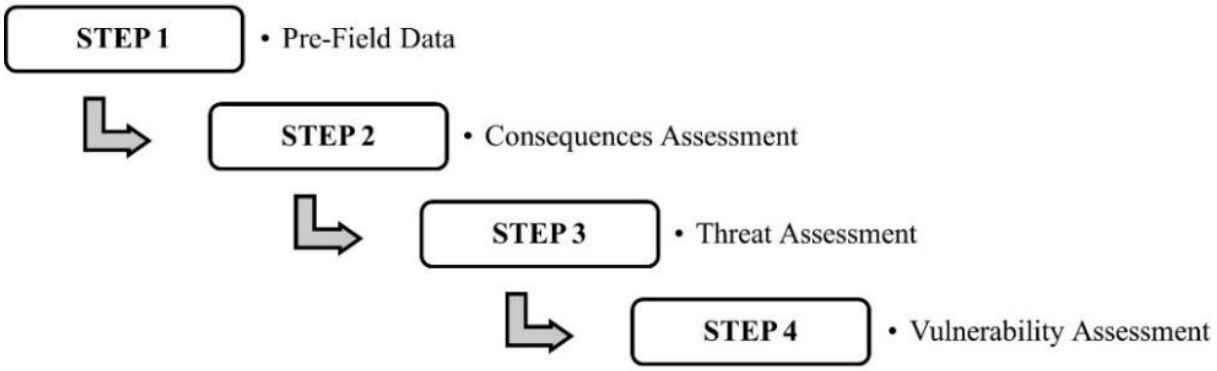


Figure 2. Assessment steps.

In this chapter, modifications of the characteristics for structural evaluation in each phase are shown, and are displayed in comparison tables (IRVS vs. K-RVS), where most of the arrangements were taken from the KDS.

2.2. Configuration of Phase I

Important attention was placed on pre-field data, as IRVS describes it as a phase with relevant building identification information and some of the most important components with high weight values.

2.2.1. Pre-Field 1

Pre-field 1 includes hazard, structure type, and resilience computations, which are essential characteristics of the assessment. K-RVS was developed with the purpose of allowing an assessment based on hazards as in the IRVS system (Table 2). However, the hazard contained in the K-RVS was reduced because of the scope of this study. Four threats were selected when focusing on the structural safety of tall buildings: earthquake, wind, blast, and fire. The assessment of a building should present at least one of these four hazards; otherwise, no outcomes will be obtained. An essential requirement for a structure is its rigidity, which aids in utilizing the overall inertia and in sustaining localized damage without widespread collapse. This requires tensile capacity and ductility in the design of the elements and their connections [28]. The structure type is one of the characteristics that play an extremely important role; therefore, an examination of tall building structure types was conducted. Consequently, in addition to the structures specified in the table of design coefficients for structural systems in KDS [27], six more structure types for tall buildings mentioned by Ali and Moon [29] were included in the K-RVS. The IRVS system states that resiliency reflects the continuity of building operations; meanwhile, the system points it out as the capacity to adapt to hazards or a transition in conditions.

Table 2. Comparison table for pre-field 1 between IRVS and K-RVS.

Pre-Field 1	IRVS	K-RVS
Hazard	Earthquake Flood Wind Blast Chemical, biological, and radiological (CBR) Fire	Earthquake Wind Blast Fire
Structure type	Wood frame Manufactured homes Steel moment frame Steel braced frame Steel light frame Steel frame with cast-in-place concrete shear walls Steel frame with unreinforced masonry infill walls Concrete moment frame Concrete shear walls Unreinforced masonry bearing walls Concrete frame with unreinforced masonry infill walls Precast concrete tilt-up walls Precast concrete frames with concrete shear walls Reinforced masonry bearing walls with wood or metal deck diaphragms Reinforced masonry bearing walls with precast concrete diaphragms	Special reinforced concrete shear wall Ordinary reinforced concrete shear wall Steel eccentrically braced frame (MRCLC [1]) Steel eccentrically braced frame (NMRCLC [2]) Special steel concentrically braced frame Ordinary steel concentrically braced frame Composite eccentrically braced frame Special composite concentrically braced frame Ordinary composite concentrically braced frame Composite steel plate shear wall Special composite shear wall Ordinary composite shear wall Special steel plate shear wall Buckling-restrained braced frame (MRCLC [1]) Buckling-restrained braced frame (MRCLC [1]) Special reinforced concrete shear wall Special steel moment frame Intermediate steel moment frame Ordinary steel moment frame Special composite moment frame Intermediate composite moment frame Ordinary composite moment frame Composite partially restrained moment frame Special reinforced concrete moment frame Intermediate reinforced concrete moment frame Ordinary reinforced concrete moment frame
	-	Outrigger structure Tube Diagrid Exoskeleton Space Truss Superframe Optional/Not from KDS
Resiliency computations	No resiliency computations are needed General Government Medical School K12 Business/Financial Retail	No resiliency computations are needed General Business/Financial Residence

[1] MRCLC: Moment resisting column-link connection [2] NMRCLC: Non-Moment resisting column-link connection.

2.2.2. Pre-Field 2

Pre-field 2 includes the number of occupants, replacement value, occupancy use, target density (zones I, II, and III), target potential (building and sector), seismic zone, geology, high wind speed, typhoon (hurricane in IRVS) frequency in the region, and soil type (Table 3). The number of occupants represents the potential casualties, which means the number of people with possible injuries or death owing to multiple hazards. The number of occupants values were taken from previous studies [14,30] with refitting considerations for tall buildings. The replacement value is the current value of construction per unit

area multiplied by the gross square meters of the building. The replacement value can be changed based on construction costs with numerous conditions and use of the building. The replacement values were obtained from previous studies [14,30]. Occupancy use is related to the function of the building. In the Building Act in Korea enforced on 10 May 2013, it is stated that uses of buildings are to be classified into twenty-eight categories, and the subcategories of the building uses in each category will be prescribed by presidential decree [31]. Occupancy use indicates the purpose for which a building is occupied. Sometimes tall buildings have multiple uses; consequently, and also for K-RVS purposes, most tall buildings to be evaluated should coincide with the classification in group 3; for example, business facilities and class I-II neighborhood living facilities. Any different facility must be introduced as others based on the previous studies [20]. Target density is defined as the number of high-value objects near the building. The distance is classified into zones 1, 2, and 3. Target density excludes the subject building.

Target potential is related to the possibility that a terror event affecting the target building will happen. The seismic zone is a distinct area of seismicity activity which indicates the frequency and location of earthquakes. In KDS, the table for regional seismicity and its spectral acceleration parameter is provided. From these, two seismic zones are recognized and taken for the study. The proximity of an active seismic fault depends on active faults within an 80 km radius of the building. IRVS refers to high wind speed zone maps as a source of information about wind speeds in a specific region. Classifications were made according to the table for basic wind speed in Korea and its corresponding map provided by KDS. The frequency of hurricanes in the northwestern pacific is normally recorded because there is no official hurricane season throughout the year. Therefore, from previous typhoon disasters that occurred in Korea, classifications per occurrence year were made. Soil type, the main parameter in the seismic resiliency, is the kind of soil/rock on which the foundation is located.

2.3. Configuration of Phase II

2.3.1. Consequences

IRVS mentions that locality/density types describe the population density and land use (Table 4). Because this study focuses on tall buildings mostly located in dense urban areas, only two categories were chosen. Operational redundancy depends on the grade to which a building can maintain a competent service and keep operational stability rather than recoverable capacity after hazards. Because the impact of physical loss shows the amount of loss after hazards, three classifications were chosen based on the scope of the study.

2.3.2. Threats

Threat assessment depends on target attractiveness, not on the likelihood of a threat, and it is related to man-made threats capable of causing loss of or damage to assets (Table 5). Therefore, the only two hazards related to these characteristics are blast and fire hazards. Site population density is defined as the number of people living near the building, excluding the population inside the building.. IRVS defines the visibility/symbolic value as the importance of a building in terms of economics, cultures, and symbols. Overall site accessibility indicates the security levels of the building to prevent hazards on the building. These characteristics were modified based on the scope of the study.

Table 3. Comparison table for pre-field 2 between IRVS and K-RVS.

Pre-Field 2	IRVS	K-RVS
Number of occupants	2000 to less than 5000	2000 to less than 4000 4000 to less than 6000
	5000 to less than 10,000	6000 to less than 8000 8000 to less than 10,000
	10,000 to less than 12,500	10,000 to less than 20,000
	12,500 to less than 15,000	20,000 to less than 40,000
	15,000 to less than 17,500	40,000 to less than 60,000
	17,500 to less than 20,000	60,000 to less than 80,000
	20,000 or more	80,000 or more
Replacement value	$15 m to less than $20 m	less than 60 billion won 60 billion won to less than 80 billion won
	$20 m to less than $150 m	80 billion won to less than 100 billion won 100 billion won to less than 200 billion won
	$150 m to less than $400 m	200 billion won to less than 400 billion won
	$400 m to less than $750 m	400 billion won to less than 600 billion won
	$750 m to less than $1 billion	600 billion won to less than 800 billion won
	$1 billion or more	more than 800 billion won
Occupancy use	Group 1	Other
	Group 2	
	Group 3	Group 3
Target density	Zone 1 Zone 2 Zone 3	
Target potential	Building Sector	
Seismic Zone	Low Medium High	
Proximity to an active seismic fault	Farther than 50 miles (80 km) from a fault active or inactive. Or within 50 miles (80 km) of an inactive fault Within 50 miles (80 km) of an active fault	
High wind speed zone	Low zone with winds of low to moderate speeds-winds below 75 mph (33.5 m/s) peak gust	Low zone with winds of low speeds-winds below 28 m/s or 100 km/h Medium-low zone with winds of moderate speeds-winds below 34 m/s or 120 km/h.
	Medium zone exposed to strong winds- winds between 75 mph (33.5 m/s) and 111 mph (49.6 m/s) peak gust	Medium zone exposed to strong winds- winds between 34 m/s (120 km/h) and 50 m/s (180 km/h).
	High building subjected to damaging winds with speeds of greater than 111 mph (49.6 m/s), generally in hurricane-prone or tornado-prone zones.	
Hurricane/typhoon frequency in the region	Never. No record of a hurricane/typhoon in the region	
	Rare. One or two hurricanes in the last 100 years	Rare. One or two typhoons in the last 70 years
	Medium. One or two hurricanes in the last 20 years	Medium Rare. One or two typhoons in the last 40 years
	Frequent. Multiple hurricanes in the last 20 years that significantly affected the region	Medium. One or two typhoons in the last 20 years Frequent. Multiple typhoons in the last 20 years that significantly affected the region
Soil Type	Hard rock	Hard Rock Rock
	Medium	Very Dense Soil or Soft Rock Stiff Soil
	Poor	Soft Soil

Table 4. Comparison table for consequences between IRVS and K-RVS.

Consequences	IRVS	K-RVS
Locality/Density type	Rural/Suburban Semi urban/Light industrial Industrial Urban Dense Urban	Urban Dense Urban
Operational redundancy	Very high High Moderate Low Very low or not capable	Very high High Moderate Low Very low or not capable
Impact of physical loss	Local Statewide Regional National International	Regional National International

Table 5. Comparison table for threat between IRVS and K-RVS.

Threat	IRVS	K-RVS
Site population density	Very low (1 person per 929 m^2) Low (1 person per 93 m^2) Moderate (1 person per 37 m^2) High (1 person per 3.7 m^2) Very high (1 person per 0.93 m^2)	Moderate (1 person per 37 m^2) High (1 person per 3.7 m^2) Very high (1 person per 0.93 m^2)
Visibility/Symbolic value	Very low Low Moderate High Very high	Low Moderate High Very high
Overall site accessibility	Inaccessible Accessible	Inaccessible Accessible

2.3.3. Vulnerability

The characteristics consist of the existing items in IRVS and additional items in K-RVS (Table 6). Five characteristics (exterior fireproof walls, seismic design categories, allowable story drift, surface roughness, and enclosures) were added to the vulnerability assessment. Nearby structural characteristics indicate the potential for additional damage in nearby structures. Slope means the slope near the building, and slope failure (landslide) can influence negative effects. The condition of the foundation refers to the overall status of the foundation. A retaining wall should withstand the soil and water pressure. Liquefaction indicates the extremes of vibration or flow of soil during earthquakes because of less consolidation. The overhang characteristic is related to occupied space and the overhang is the distance between the exterior enclosure and the inside face. Horizontal irregularity (plan irregularity) contains re-entrant corners of buildings. This may cause unexpected twists around the vertical axis. In addition, irregular vertical configurations may cause dangerous stress concentrations. Based on KDS, the horizontal and vertical irregularity characteristics were considered in K-RVS. Wall type is defined by facades; screeners should decide this by site-visiting or asking the designers. The windborne debris impact protection characteristic should be considered in the most dangerous accident. Bay means the spacing between structural columns, and unbraced column height. Column height is related to the stability of structures and publicly accessible columns may be a target of terror. Lateral systems are mainly designed for resisting lateral force. Transfer girders are a kind of deep depth girder to transfer the huge loads that occur by discontinuous columns. Structural

enhancement refers to the improving strength or stiffness of the structural members. Short columns or walls allow significant stresses which during an earthquake may crack or collapse. The seismic design or retrofit can be confirmed seismic design or retrofit from. Long-span roof members are vulnerable to the uplift of winds passing through the door or window. Topping slabs are finishings above structural slabs or components. Adjacent buildings, which are extremely close, may influence each other during hazards.

Table 6. Comparison table for vulnerability between IRVS and K-RVS.

Vulnerability	IRVS	K-RVS
Nearby structures (Underground or adjacent)	None Small Medium Major	
Topography/Slopes	Flat or terraced with adequate setbacks Light slope Moderate slope Steep slope	
Condition of foundation	Excellent Medium Poor	
Retaining walls	Noon Good Condition Moderate Condition Poor Condition	
Potential of soil liquefaction	None Low Medium High	
Overhang	None <5 feet (<1.5 m) ≥5 feet, <10 feet (1.5–3 m) ≥10 feet, <15 feet (3–4.6 m) ≥15 feet (>4.6 m)	Less than 2 m From 2 m to less than 3 m From 3 m to less than 5 m More than 5 m
Horizontal (plan) irregularity	No. No horizontal irregularities Yes. One or more horizontal irregularities	Torsional irregularity Re-entrant corners Diaphragm discontinuity Out-of-plane offsets Nonparallel Systems
Vertical irregularity	No. No vertical irregularities Yes. One or more vertical irregularities	Soft story Irregularity Vertical geometric irregularity Irregularity in lateral force-resisting vertical elements Discontinuity in strength-weak story

Table 6. *Cont.*

Vulnerability	IRVS		K-RVS	
Building height	More or equal to 150 feet (>45.7 m) Less than 200 feet (<61)	<12 floors 12 to 15 floors	Intermediate Large-Scale Building (60 m to 120 m)	15 to 30 floors
	200 feet to less than 500 feet (61 m–52.4 m)	16 to 39 floors	Large Scale Building (120 m to less than 200 m)	30 to 50 floors
	500 feet to less than 800 feet (152.4–243.8 m)	40 to 60 floors	High Rise Building (200 m to 300 m)	50 to 80 floors
	800 feet to less than 1000 feet (243.8–304.8 m)	60 to 80 floors	Sky-Scraping Building (More than 300 m)	more than 80 floors
	More than 1000 feet (>304.8 m)	>80 floors		
Wall type	Cast in place reinforced concrete Curtain wall/metal framing Precast panels/reinforced masonry Massive unreinforced masonry Light frame or slender unreinforced masonry (brick) Unreinforced masonry			
Windborne debris impact protection	Post-benchmark year All other buildings			
Number of bays in the short direction	five or more bays three or four bays Less than three bays			
Column spacing	Less than 15 feet 15 feet to less than 25 feet 25 feet to less than 40 feet 40 feet to less than 60 feet 60 feet or more		Less than 4 m 4 m to less than 8 m 8 m to less than 12 m 12 m to less than 18 m 18 m or more	
Unbraced column height	Less than 12 feet 12 feet to less than 24 feet 24 feet to less than 36 feet 36 feet or more		Less than 4 m 4 m to less than 8 m 8 to less than 12 m 12 m or more	
Publicly accessible column	No publicly accessible columns Yes, protected. Behind and separated from the building facade and enclosed by and architectural cover that extends at least 6 inches (15 cm) from face of column Yes, massive. Height-to-width ratio of less than five Yes, slender. Height-to-width ratio of more than five			
Number of lateral systems (redundancy)	Greater than four Four Three Two One			
Transfer girder conditions	None. All columns are continuous from roof to foundation Interior girder supporting one column. The girder spans an interior space and supports one column above Interior girder supporting more than one column. The girder spans an interior space and supports more than one column above Exterior girder supporting one column. The girder is along the perimeter of the building and supports one column above Exterior girder supporting more than one column. The girder is along the perimeter of the building and supports more than one column above			

Table 6. *Cont.*

Vulnerability	IRVS	K-RVS
Structural enhancements and weaknesses	Hardened. Designed to resist the effects of an explosive attack Robust. Designed or retrofit to meet current extreme loading conditions related to high levels of hurricane or earthquake loads or designed to resist progressive collapse None. No structural enhancements or weaknesses in the other attribute options (most common) Marginal. Designed using versions of codes that are no longer considered acceptable for meeting serviceability conditions. Designed using materials or connections that have been shown to perform poorly in abnormal loading situations. Building is not well maintained. Substandard. Designed to a level that has little, if any, reserve strength to withstand any abnormal loads without catastrophic failure.	
Short columns or walls	None Few (one or two) in single floor Several (more than two) in single floor Few (one or two) in several floors Several (more than two) in several floors	
Seismic design/Retrofit	No Yes	
Roof span	20 feet or less more than 20 feet to less than 40 feet 40 feet or more	6 m or less more than 6 m to less than 12 m 12 m or more
Topping slabs	Present Missing	
Adjacent building separation	No adjacent buildings Adequate (more than six inches) Not adequate (less than six inches)	
Fireproof walls	Not apply	Yes No
Seismic design category	Not apply	A B C D
Allowable story drift	Not apply	S (0.010 h_{sx} [1]) 1 (0.015 h_{sx} [1]) 2 (0.020 h_{sx} [1])
Surface roughness	Not apply	A (Large city center with closely spaced tall buildings higher than 10-story) B (City with closely spaced residential houses with heights of 3.5 m or so or scattered medium rise buildings) C (Open terrain with scattered obstructions with heights of 1.5 to 10 m or so or scattered low-rise buildings) D (Exposed open terrain with few obstructions or scattered obstructions less than 1.5 m in height or grassland, beach, airport, etc.)
Enclosure	Not apply	Enclosed Partially open/without dominant opening Partially open/with dominant opening Open Building

[1] h_{sx}: Allowable story drift.

Five new vulnerability characteristics (exterior fireproof walls, seismic design category, allowable story drift, surface roughness, and enclosure) that supplement K-RVS were proposed. Articles 50 and 51 (fireproof structure and fireproof wall of buildings, and buildings

in fire prevention districts) in the Korean Building Act [31] state that the main structural parts and external walls of each building in a fire prevention district should be of a fireproof structure, including apartment houses. KDS [27] maintains that all structures should be assigned to a seismic design category based on their seismic use group and design spectral acceleration. In addition, KDS describes story drift design as the difference in the displacements of the center of mass at the top and bottom of the story under consideration. Surface roughness is defined as the shorter frequency of real surfaces relative to troughs and is widely used for wind environment evaluation. The building enclosure defines the space it encloses. However, more than the building's outer dimension, the building enclosure is the barrier that separates the external climatic environment, in this case, wind, from the interior. The properties of the building enclosure have a significant effect on efficiency and functionality against the wind.

3. Methodology of the Weight Values

A scoring system was created to evaluate the characteristics in K-RVS. Table 7 shows the different categories and the values for each one, from weight values with very high priority (100) to medium-important weight values (5).

Table 7. Weight values in K-RVS.

Category	Weight Value (W)
Very Highly Important	100
Highly Important	80
Very Important	25
Relevant	15
Important	10
Medium Important	5

Thus, a score for each characteristic was given, depending on its influence and weight in compromising building security (Table 8). If a feature does not affect the corresponding hazard, a zero score for that characteristic is awarded. The heavily weighted characteristics mentioned in the structural part of IRVS, i.e., target potential building, target density, soil type, structure type, overall site accessibility, topography/slopes, transfer girder conditions, and seismic design/retrofit, are awarded high values.

In addition to the principal characteristics, another classification was made with the same purpose as the previous; however, this classification was evaluated from 1 to 5 (score), from very low to very high risk, passing through low, moderate, and high risk (Table 9).

To determine the final values of each hazard, the aforementioned weight values and scores were introduced into Equations (1) and (2) as follows:

$$h = \frac{\sum_{i=1}^{48} W_i S_i}{\sum_{i=1}^{48} 5W_i} \times 100 \quad (1)$$

$$D = \frac{\alpha h_e + \beta h_w + \gamma h_b + \delta h_f}{\alpha H_e + \beta H_w + \gamma H_b + \delta H_f} \times 100 \quad (2)$$

where h is the score for each hazard, W is the weight value presented in Table 7, S is the score presented in Table 9, D is the final score for disaster assessment of tall buildings focusing on structural safety, h_e is the score from the earthquake, h_w is the score from the wind, h_b is the score from the blast, h_f is the score from the fire, H_e is the highest score from the earthquake, H_w is the highest score from the wind, H_b is the highest score from the blast, H_f is the highest score from the fire, α is the weight index for earthquakes (8.5), β is the weight index for winds (10), γ is the weight index for blasts (9), and δ is the weight index for fire (5.5). These weight indices were obtained based on exploration data from IRVS.

Table 8. Characteristics of weight values in K-RVS.

Component		No.	Characteristics	Earthquake	Wind	Blast	Fire
Pre-field 1		1	Structure type	80	100	80	100
		2	Number of occupants	10	15	15	25
		3	Replacement value	15	5	15	10
Pre-field 2		4	Occupancy use	-	-	15	25
		5	Target density: Zone I	-	-	15	25
		6	Target density: Zone II	-	-	15	15
		7	Target density: Zone III	-	-	15	15
		8	Target potential: Building	-	-	25	25
		9	Target potential: Sector	-	-	10	25
		10	Seismic zone	25	-	-	10
		11	Proximity to an active seismic fault	25	-	-	10
		12	High wind speed zone	5	10	-	-
		13	Typhoon frequency in the region	-	25	-	-
		14	Soil type	25	-	-	-
Consequences		15	Locality/Density type	10	10	10	15
		16	Operational redundancy	10	10	10	10
		17	Impact of physical loss	10	10	10	10
Threat		18	Site population density	-	-	10	15
		19	Symbolic value	-	-	10	15
		20	Overall site accessibility	-	-	25	25
Vulnerability	Site	21	Nearby structures	15	5	15	10
		22	Topography/Slopes	25	25	25	-
		23	Condition of foundation	15	-	-	-
		24	Retaining walls	10	5	-	-
		25	Potential of soil liquefaction	15	-	-	-
	Architectural	26	Building height	10	15	25	15
		27	Overhang	10	5	10	5
		28	Horizontal irregularity	15	5	-	-
		29	Vertical irregularity	15	5	-	-
	Structure	30	Number of bays in the short direction	5	5	15	-
		31	Column spacing	5	5	10	-
		32	Unbraced column height	5	5	10	-
		33	Publicly accessible column	-	-	15	5
		34	Transfer girder conditions	25	25	15	-
		35	Structural enhancements and weaknesses	5	5	5	-
		36	Number of lateral systems	5	10	5	-
		37	Short columns	15	5	-	-
		38	Seismic retrofit	25	10	15	-
		39	Roof span	-	5	-	-
		40	Topping slabs	5	5	-	-
		41	Building separation	15	-	-	-
	Building Enclosure	42	Wall type	5	10	15	-
		43	Windborne debris impact Protection	-	10	10	-
	New	44	Exterior fireproof walls	-	-	15	15
		45	Seismic design category	5	-	-	-
		46	Allowable story drift	5	-	-	-
		47	Surface roughness	-	5	-	5
		48	Enclosure	-	5	-	15

Table 9. Score values of the classification.

Classification	Scores (S)
Very low	1
Low	2
Moderate	3
High	4
Very High	5

The final score (*D*) for disaster assessment of tall buildings will be explained as values with percentages, which can be classified by colors, as shown in Table 10.

Table 10. Color table depending on the disaster assessment of tall buildings.

Color	Final Score (*D*)	Disaster Assessment
	0–30%	Low risk
	30–50%	Moderate risk
	50–70%	High risk
	70–100%	Very high risk

4. Verification and Discussions

4.1. K-RVS Access System

The K-RVS access system database was created using Microsoft Access, a data management system in IRVS, which is a very useful tool when many data tables are being used. The K-RVS database allows the creation of several reports from different buildings to evaluate and present results simultaneously, as shown in Figure 3.

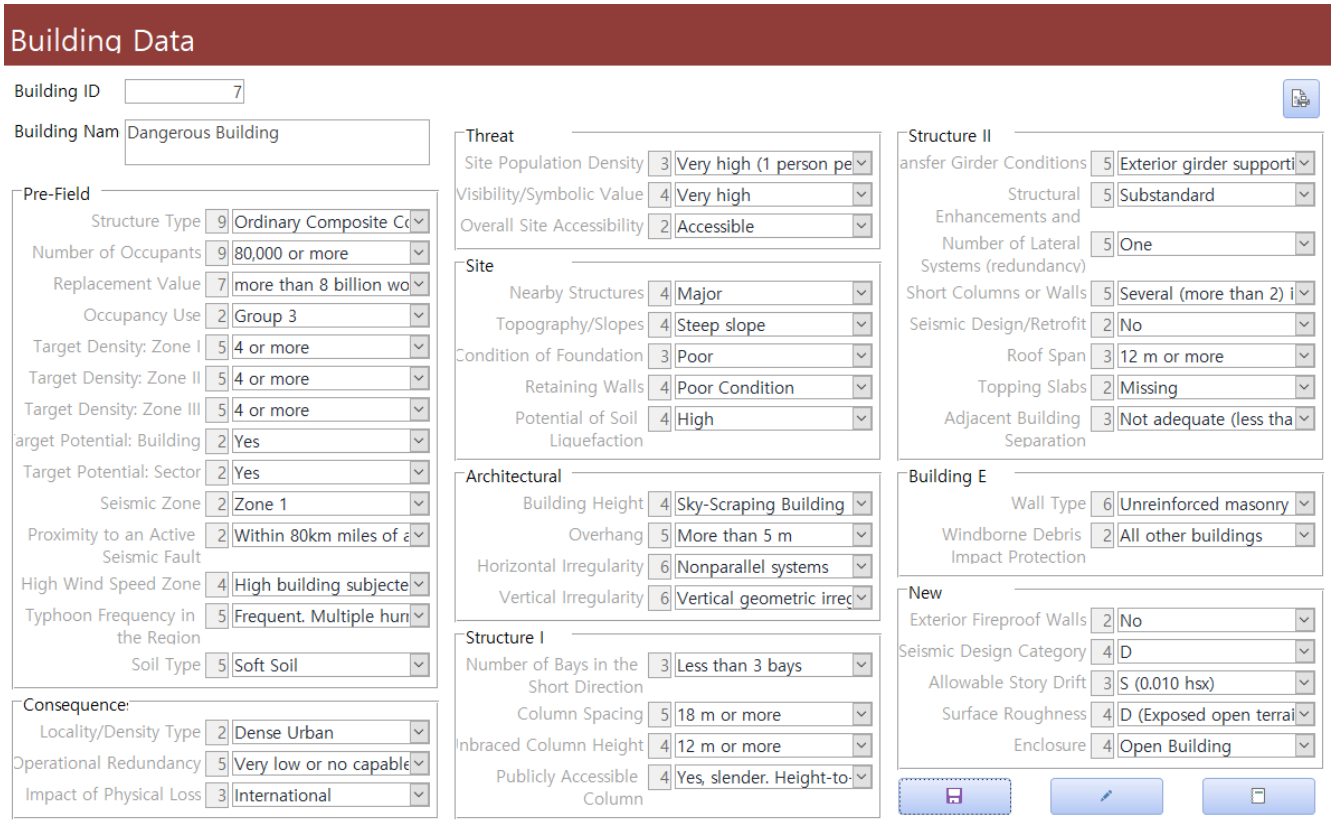


Figure 3. Example of K-RVS access system.

4.2. Building Examples

A comparison between K-RVS and IRVS was done with three different building examples; two imaginary and one real. Because it was extremely difficult to obtain detailed information on tall buildings, two imaginary buildings based on existing buildings with little data and an existing building with sufficient data were selected for verification. The existing building is the KLI 63 building [32], which is located in Seoul and has a height of 249.6 m and 63 floors, including roof and mechanical facility floors. It was built in 1985, and is currently used by commercial offices. The information on KLI 63 and the two imaginary buildings is presented in Table 11.

Table 11. Information on the KLI 63 building and two imaginary buildings in IRVS and K-RVS.

Component	No.	Characteristics	KLI 63 Building		Imaginary Building 1		Imaginary Building 2	
			IRVS	K-RVS	IRVS	K-RVS	IRVS	K-RVS
Pre-field 1	1	Structure type	Steel Moment Frame	Ordinary Steel Moment Frame	Steel Moment Frame	Ordinary Steel Moment Frame	Steel Frame with Unreinforced Infill Walls	Ordinary Steel Concentrically Braced
	2	Number of occupants	10,000–12,500	10,000–20,000	17,500–20,000	10,000–20,000	17,500–20,000	10,000–20,000
	3	Replacement value	$20 M–$150 M	Less than 60 B	$20 M–$150 M	Less than 60 B	$20 M–$150 M	60 B to less than 80 B
Pre-field 2	4	Occupancy use	Group 3	Group 3	Group 3	Group 3	Group 3	Group 3
	5	Target density: Zone I	2	2	0	0	>4	4 or more
	6	Target density: Zone II	1–3	1–3	4–6	4–7	>10	10 or more
	7	Target density: Zone III	1-6	1-6	13-19	13-19	>20	20 or more
	8	Target potential: Building	Yes	Yes	Yes	Yes	Yes	Yes
	9	Target potential: Sector	Yes	Yes	No	No	Yes	Yes
	10	Seismic zone	Low	Zone 2	Medium	Zone 2	High	Zone 1
	11	Proximity to an active seismic fault	Not near fault	Farther than 80 km from a fault	Not Near Fault	Farther than 80 km from a Fault	Near Fault	Within 80 km from a Fault
	12	High wind speed zone	Low	Medium-Low Zone	Medium	Medium (Exposed to Strong Winds)	Medium	Medium (Exposed to Strong Winds)
	13	Typhoon frequency in the region	Frequent	Frequent	Rare	Medium-Rare	Medium	Medium (1 or 2 in the last 20 years)
	14	Soil type	Hard Rock	Hard Rock	Medium	Very Dense Rock	Medium	Stiff Soil
Consequences	15	Locality/Density type	Urban	Urban	Dense Urban	Dense Urban	Dense Urban	Dense Urban
	16	Operational redundancy	High	High	High	High	Low	Low
	17	Impact of physical loss	National	National	Regional	Regional	National	National
Threat	18	Site population density	High	High	High	High	Very High	Very High
	19	Symbolic value	High	High	High	High	Very High	Very High
	20	Overall site accessibility	Accessible	Accessible	Accessible	Accessible	Accessible	Accessible

Table 11. *Cont.*

Component		No.	Characteristics	KLI 63 Building		Imaginary Building 1		Imaginary Building 2	
				IRVS	K-RVS	IRVS	K-RVS	IRVS	K-RVS
Vulnerability	Site	21	Nearby structures	None	None	Medium	Medium	Major	Major
		22	Topography/Slopes	Flat	Flat	Moderate Slope	Moderate Slope	Steep	Steep
		23	Condition of foundation	Excellent	Excellent	Excellent	Excellent	Poor	Poor
		24	Retaining walls	None	None	Moderate Condition	Moderate Condition	Moderate Condition	Moderate Condition
		25	Potential of soil liquefaction	Low	Low	Low	Low	Medium	Medium
	Architectural	26	Building height	800–1000 ft (60–80 floors)	High Rise Building (200 m to 300 m)	200–500 ft	Intermediate Large Scale (60–120 m)	500–800 ft	High Rise Building (200–300 m)
		27	Overhang	None	None	5–10 ft	From 2 m to less than 3 m	>15 ft	More than 5 m
		28	Horizontal irregularity	None	None	Yes	Re-Entrant Corners	Yes	Torsional Irregular-ity
		29	Vertical irregularity	None	None	Yes	Irregularity in Lateral Force	Yes	Soft Story
	Structure	30	Number of bays in the short direction	3–5	3 or 4 bays	3–5	3 or 4 Bays	<3	Less than 3 Bays
		31	Column spacing	15–25 ft	4 m to less than 8 m	15–25 ft	4 m to less than 8 m	>60 ft	18 m or More
		32	Unbraced column height	12–24 ft	4 m to less than 8 m	24–36 ft	8 m to less than 12 m	>36 ft	12 m or more
		33	Publicly accessible column	None	None	Yes, Massive	Yes, Massive	Yes, Slender	Yes, Slender
		34	Transfer girder conditions	None	None	Int. Girder Sup.1 Column	Int. Girder Sup.1 Column	Ext. Girder Sup. > 1 Column	Ext. Girder Sup. > 1 Column
		35	Structural enhancements and weaknesses	None	None	None	None	Marginal	Marginal
		36	Number of lateral systems	1	One	3	Three	2	Two
		37	Short columns	None	None	Few in a Single Floor	Few in a Single Floor	Few in Several Floors	Few in Several Floors
		38	Seismic retrofit	Yes	Yes	No	No	No	No
		39	Roof span	≤20 ft	6 m or less	>20–<40 ft	More than 6 m less than 12 m	>40 ft	12 m or more
		40	Topping slabs	Present	Present	Present	Present	Missing	Missing
		41	Building separation	No adjacent buildings	No adjacent buildings	Adequate	Adequate	Adequate	Adequate
	Building Enclosure	42	Wall type	Curtain Wall	Curtain Wall	Light frame	Light frame	Curtain Wall	Curtain Wall
		43	Windborne debris impact Protection	All other buildings	All other buildings	All Others	All Others	All others	All Others
	New	44	Exterior fireproof walls	N/A	Yes	N/A	No	N/A	Yes
		45	Seismic design category	N/A	B	N/A	A	N/A	B
		46	Allowable story drift	N/A	1 (0.015 h_{sx})	N/A	2 (0.020 h_{sx})	N/A	2 (0.020 h_{sx})
		47	Surface roughness	N/A	A (large city)	N/A	B	N/A	A (large city)
		48	Enclosure	N/A	Partially Open (without dominant opening)	N/A	Partially Open (without dominant opening)	N/A	Enclosed

4.3. Results and Discussions

The scores for each hazard (h) and the final score (D) from the K-RVS and IRVS assessment systems for the KLI 63 building and two imaginary buildings are shown in Table 12 and Figure 4. The scores and overall trends of the KLI 63 building and two imaginary buildings in K-RVS and IRVS were similar, except for earthquake and total scores. This is why characteristics focusing on earthquake weight values, such as soil type, horizontal and vertical irregularity, seismic design category, and allowable story drift, were segmentalized. In addition, K-RVS determined that the earthquake risks of the example buildings were quite higher than those of IRVS because Korea is in a low-moderate seismic zone where weaker earthquakes occur than in the U.S. For fire and blast hazards, the scores by both systems were slightly different owing to new characteristics. For wind hazards, the scores showed inconsistent results because characteristics related to wind speed in K-RVS were more segmentalized owing to various terrain features. The scores for fire in K-RVS are lower than those in IRVS because the law related to high-rise buildings in Korea focuses on the prevention and egress of fire accidents. Besides fire, all other scores in K-RVS were higher than those in IRVS, which means that disaster assessments in Korea by IRVS were underestimated. Finally, considering the KDS and Korean conditions, the K-RVS modified from IRVS can rapidly and conservatively conduct disaster assessments of tall buildings under multiple hazards.

Table 12. Score by each hazard and final score from K-RVS and IRVS.

Hazards	System	KLI 63 Building	Imaginary Building 1	Imaginary Building 2
Fire	K-RVS	76.32	75.17	90.34
	IRVS	79.06	79.84	92.93
Blast	K-RVS	65.57	75.67	91.75
	IRVS	56.93	65.63	84.75
Earthquake	K-RVS	44.30	62.80	89.25
	IRVS	8.08	46.35	70.26
Wind	K-RVS	66.39	75.00	88.61
	IRVS	67.02	53.31	74.25
Total	K-RVS	61.70	71.86	90.03
	IRVS	47.85	54.49	84.38

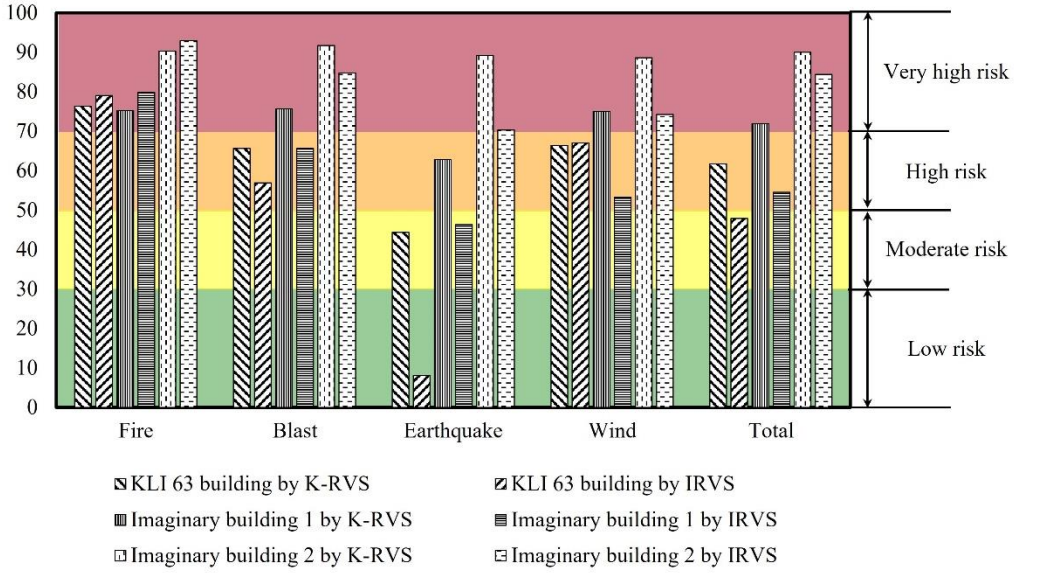


Figure 4. Score by each hazard and final score from K-RVS and IRVS.

5. Conclusions

This study introduces a Korean rapid visual screening (K-RVS) system that can rapidly perform disaster assessment of tall buildings subjected to four major disasters: fire, blast, earthquake, and wind. The K-RVS system was based on the integrated rapid visual screening (IRVS) system provided by FEMA in the U.S., and modified according to the Korean Design Standard (KDS) and Korean conditions. The K-RVS system includes two pre-field data: consequences, threats and vulnerability characteristics, which are classified into several categories. These categories with each weight value were used to score each hazard and calculate the final score for disaster assessment. The KLI-63 building and two imaginary buildings, based on existing buildings with little information, were selected to test the K-RVS system. The scores and overall trends of the three buildings by K-RVS and IRVS were similar, except for earthquakes. Because of segmentalized characteristics focusing on earthquakes in the K-RVS, the scores differed significantly. Finally, the scores for each hazard and final scores by the K-RVS were lower than those in IRVS because the IRVS system underestimated the disaster assessment of tall buildings in Korea, owing to the gap between the KDS and Korean conditions. For example, segmentized characteristics in K-RVS aim to evaluate the structural assessment of the tall building in Korea because Korea is in a low-to-moderate seismic zone, which is different from the IRVS characteristics. This paper can inspire other countries with different multi-hazard conditions from IRVS to suggest a new RVS system for their own multi-hazard conditions.

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