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A Study on a Risk Assessment Method and Building Simulation for the Development of a Korean Integrated Disaster Evaluation Simulator (K-IDES) for High-rise Buildings

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Abstract The purpose of this study is to establish a method for assessing a building's risk against disaster, tentatively named the Korean integrated disaster evaluation simulator (K-IDES). Based on previous studies, FEMA's risk management series and FEMA IRVS are selected as case studies for developing a frame work of K-IDES, through the comparative analysis of domestic building design guides, codes, and special acts related to disasters, in order to develop a risk assessment methodology for quantitative results. The assessment method consists of a classification system and calculating risk, and a simulation applying the developed checklist in K-IDES to similar types of high-rise buildings will be conducted to validate its accuracy. The final goal is to systemize an integrated risk management in a high-rise building against disasters for the purpose of recognizing vulnerable areas from the beginning of the design process and reinforcing it from potential threats after construction.

Keywords: Risk assessment method for high-rise buildings, Building design against disasters, FEMA IRVS

1. INTRODUCTION

1.1 Purpose and Background

Currently, Korea ranks 11th in the world in the density of high-rise buildings in (buildings more than 150 m in height), with approximately 400 such buildings (under construction or completed, based on the 2018 statistics of The Council on Tall Buildings and Urban Habitat). The concentration of multi-function buildings in urban areas and the continuous increase in the number of high-density and functionally complex high-rise buildings in older cities can become a threat in a disaster, specifically if buildings and property incur physical damage. For example, the damage by the collapse of the World Trade Center (WTC) by the 9/11 terrorist attacks in New York City also spread to the surrounding high-rise buildings, which amplified the consequences of the explosion. The facade and structure were further damaged by collapsing debris, and fire caused more loss and destruction. In order to reduce risk and loss in cases of disaster, domestic studies have been conducted to improve the performance of buildings against individual disasters by strengthening the standards for material, equipment and evacuation against fire, as well as the reinforcing of structural standards due to recent seismic occurrences. However, most of these studies have focused on the partial improvement of evacuation-oriented buildings for individual disaster scenarios. Therefore, studies on evaluation criteria, evaluation methods, and design guides for reinforcing buildings against various catastrophic disaster risks are currently insufficient and require further research. Thus, this study aims to construct a disaster risk assessment model (tentatively named K-IDES) for Korean high-rise buildings to reflect this domestic reality, and preliminary studies are conducted on the risk management series of the Federal Emergency Management Agency (FEMA) in the US, which can guide risk management and the quantitative analysis of it through building a risk assessment system against various disasters. Explosive terror, fire, earthquake, and typhoon, all of which are likely to occur

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in Korea, were selected as study scenarios and a risk assessment method of K-IDES was established by comparing and analysing the evaluation method derived from the FEMA case study and the applicable part of the item and domestic building codes, guidelines, and special acts related to disasters. Taking these previous studies, as a foundation, this study derives criteria, evaluation items, and evaluation methods in order to assess the risk of highrise buildings against disasters and the simulation results for actual urban highrise buildings in Korea obtained using the evaluation method are presented. In addition, the results of this study propose a research direction for improving the accuracy and utilization of evaluation models in the next step.

1.2 Methods

1.2.1 Analysis of precedent research

The concept of risk assessment for disaster in buildings is established through an analysis of the contents of the design guide, risk assessment method, and reference manual for risk prevention for buildings against terrorism that were developed by the Federal Emergency Management Agency (FEMA) of the Department of Homeland Security (DHS). The specific method used to evaluate risk against disaster in the development of K-IDES has been applied to the evaluation criteria, evaluation quantification and evaluation result analysis based on FEMA IRVS for integrated risk assessment against various disasters.

1.2.2 Analysis of domestic building guides and evaluation criteria related to disaster

In order to develop the evaluation criteria and evaluation items for domestic buildings, the High-Rise Building Design Guidelines of the Seoul Metropolitan Government; Anti-Terrorism Building Design Guidelines in Multi-purpose facilities of the Ministry of Land, Infrastructure and Transportation, the SPECIAL ACT ON MANAGEMENT OF DISASTERS IN SUPER HIGH-RISE BUILDINGS AND COMPLEX BUILDINGS WITH UNDERGROUND CONNECTIONS; and the Preliminary Disaster Impact Assessment Consultation guidelines of the Ministry of Public Safety and Security are all analysed through classification by items and compared by the contents of provision. The reviewed results are then used as guidelines to develop the detailed evaluation criteria for K-IDES risk assessment.

1.2.3 Development of check list for K-IDES risk assessment

The first step involves checking the classification system of the risk assessment field in IRVS evaluation system while excluding resilience, and an evacuation area was newly established to constitute the evaluation system to reflect the difference of standards between the two countries in the evacuation space. The second level of assessment items in the category classification system is centred on the planning elements of buildings, and the details of each item reflecting domestic standards are prepared. Finally, the criteria that can be selected for each item are divided into five attribute options.

1.2.4 Establish a method to quantify the weight and risk by items for K-IDES

Risk assessment quantifies the ratio of disasters through expert interviews and derives the application value by adjusting the ratio among disasters. The choice value for each item is based on an isometric scale of five intervals and uses the uniform scale for each item, but items are differentiated through applying weighted values to the important items. The selection of weighted items and the determination of weights are made by prioritizing the important items through group interviews of experts and the weights of the selected items are determined by using the frequency of item selection by the experts.

1.2.5 Test building simulation by using K-IDES

In order to evaluate K-IDES, the assessed result is analysed through simulations applying K-IDES against high-rise buildings of similar types.

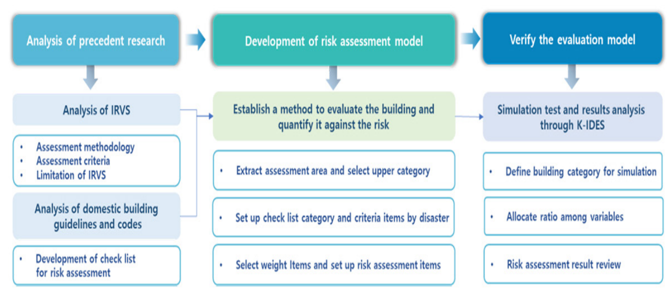

Figure 1. The framework of the study

In this paper, the evaluation methods and simulation results will be presented by using the developed research based on the first and second precedent studies mentioned above.

2. ANALYSIS OF PRECEDENT RESEARCH

2.1 FEMA guides for protecting buildings related to various disasters

FEMA has published various guides to risk management which can be applied to building design and operation by disasters to ensure safety in the event of a disaster. In a previous study, among the various FEMA guides, the guides related to the risk assessment of urban high-rise buildings were selected and classified according to the purpose of usage and the related disaster. These were used to establish an initial plan to develop a method for evaluating risk against disaster in high-rise buildings.

2.2 Analysis of FEMA IRVS

In FEMA IRVS, the evaluation target is a general building which has no restriction by region and usage. The main composition of risk assessment is based on an analysis of three factors: Consequence (C), Threat (T), and Vulnerability (V).

The first, Consequence(C), is the assessment of the degree of

Table 1. Classifications related to high-rise buildings by the FEMA guides

No.	Title	Purpose		Manmade Hazard			Natural Hazard		
		DG	RA	B	F	C	SE	ST	FI
389	Primer for Design Professionals: Communicating with Owners and Managers of New Buildings on Earthquakes	■					•		
BIPS 04	Integrated Rapid Visual Screening of Buildings		■	•	•	•	•	•	•
426/ BIPS06	Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings	■	■	•	•	•			
427	Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks	■		•	•	•			
430	Site and Urban Design for Security: Guidance Against Potential Terrorist Attacks	■		•	•	•			
452	Risk Assessment/ A How-To Guide to Mitigate Potential Terrorist Attacks Against Buildings		■	•	•	•			
454	Designing for Earthquakes	■					•		
455	Handbook for Rapid Visual Screening of Buildings to Evaluate Terrorism Risk		■	•	•	•			
459	Incremental Protection for Existing Commercial Buildings from Terrorist Attack: Providing Protection to People and Buildings	■							
543	Design Guide for Improving Critical Facility Safety from Flooding and High Winds	■					•		
P- 154	Rapid visual screening of buildings for Potential Seismic Hazards		■				•		
P- 155	Rapid visual screening of buildings for Potential Seismic Hazards: Supporting Documentation		■				•		
P-749	Planning Earthquake Resistant Design Concepts	■					•		

RA: Risk Assessment, DG: Design Guide, B: Blast, F: Fire, C: CBR. F: Fire, SE: Seismic, ST: Storm, FL: Flood

damage to the building (property) and the loss of the building operating system due to the disaster. The second, Threat (T), is the assessment of the degree of hazards to natural disasters, social disasters, potential events, signs, and behavioural threat factors that lead to injury to an asset, individual, or organization. Finally, the third, the Vulnerability (V), consists of assessments of the vulnerable elements of the building that can increase the damage to an asset in the event of a disaster. The risk level is calculated by multiplying the evaluated C, T and V values to sum up the value of each item in Consequence, Threats, and Vulnerability by disaster. The weighting items are specified, but distinct values for weights are not indicated. In the risk evaluation aspect, except for core infrastructure such as hospitals, schools, and critical facilities, it is difficult to derive differentiated results when evaluating buildings with similar uses. Particularly, since the evaluation items in Fire, Security and Cyber Security of Vulnerability consist of the qualitative analysis contents of buildings, the error rate is highly dependent on the evaluator's subjective choices. The number of options in most of the evaluation items are limited to two, unlike the other items which have five selections of five or more and thereby these evaluations reduce the sensitivity and accuracy of the risk assessment. In addition, the evaluation items with high weights of regional characteristics and environmental indicators of C and T differ from the domestic high-density characteristics in urban areas, and the frequency and intensity of earthquake and typhoons in Korea and the direct application of IRVS' evaluation items to the analysis of domestic cases is limited. Based on this research, the domestic risk assessment model is devised for the differential comparison by deciding the criteria for evaluating object, deleting the items that are difficult to apply in IRVS, and analysing the domestic standards related to the evaluating object.

Table 2. FEMA IRVS composition and risk assessment method against disasters

Category	Details		No. (%)	Remark
Evaluation area	Pre-field		18(15%)	Total questions: 120 * Pre-field contents are included in C, T and V * No separate classification system for the evacuation area for difference of concept
	Consequence		3(2.5%)	
	Threats		3(2.5%)	
	Vulnerability		91(76%)	
	Resilience		23(19%)	
Disaster Assessment Scenario	Man made hazards	Blast	79(66%)	Internal and external explosive attack
		CBR	63(54%)	Internal and external release
		Fire	48(40%)	Incidental, resulting from blast and seismic
	Natural hazards	Seismic	69(58%)	Ground shaking and failure
		Wind	71(59%)	Hurricane, Tornado, High wind
		Flood	51(43%)	Stillwater, Velocity Surge
Evaluation method	Weighted Item Selection		- Selection of weighted items by assigned expects' consultation by FEMA committee	
	Weighted Value Selection		- By assigned expert consultation, weighted by items - Unequal split for the attribute option value by items	
	Risk Assessment		- Deriving risk value to apply the differentiated correction factor by multiplying the sum of C, T and V by disaster scenarios	
	Scenario Assessment by Disaster		- Using the risk evaluation formula to apply the correction coefficient that varies according to the maximum and minimum values among C, T, and V	
	Integrated Assessment		- Using integrated risk evaluation formula to apply the conversion coefficient after summing the risk by disaster scenario	

3. DEVELOPMENT OF K-IDES

3.1 Analysis of domestic building guides and evaluation criteria related to disaster

The main items in the upper level category for the risk assessment of K-IDES are based on the classification criteria for risk assessment in general buildings outlined in FEMA IRVS. The K-IDES check points for risk assessment by the upper level category are developed by comparing and analysing the FEMA IRVS evaluation contents, the domestic preliminary impact assessment's regulation, the terror prevention design guideline, the domestic fire prevention standard, Korean building codes, and design guidelines related to disasters.

3.2 Establish a method to quantify the weight

The K-IDES disaster risk assessment is based on FEMA IRVS's individual risk assessment and integrated risk assessment formulas. K-IDES calculates the Consequence, Threats, and Vulnerability values in order to ultimately sum up each item by disaster scenario, and the individual risk is calculated using the following formula. The risk values for individual disasters exclude the interrelationships between disasters. The integrated risk is summed with Ri by threat scenario. The calculation formula derives the average risk value based on the concept of P-Norm in linear algebra.

Table 3. Through analysis of check point between FEMA IRVS and domestic guidelines and codes, K-IDES check point plan

Upper Level	FEMA IRVS check point review	Domestic guidelines & codes check point review	K-IDES check point by category
ENV.	- Community loss after disaster - Cause potential harm factors such as seismic, flood, and storm frequencies	- Application of Special Acts and anti-terrorism design guide in case of planning buildings over floor area of 20,000㎡or 50 floors	- Building size selection for evaluation against disaster - Environmental index - Land type & population density - Asset value
SITE	- Vehicle approach distance around site - Perimeter boundary design for visibility and access control - Underground & surrounding structure for security	- Securing passage and space in site for fire fighting vehicle - Site entrance gate and parking lot planning - Plans for entry and exit of vehicles and pedestrians considering security	- Possibility of evaluating vehicles' stop and rush around the site - Adequate space for fire-fighting vehicles inside the site - Evaluation of vehicle's and pedestrian's access control and control measures
ARC.	- Building height, volume and floor plan type - Control way of vehicle and pedestrian access - Parking lot, interior space planning to expose visitors	- To minimize damage from explosions, building shape and interior space planning suggestions - Space planning with circulation system to pass through certain check point	- Building volume and floor plan type - Underground parking lot plan to minimize damage from arson & blast - Separation of major facilities from explosive hazard space
ENV.	- Elevation irregularity - Glass usage rate in envelope - Roof form & slope	Usage recommendations for glass and finishing materials considering scattered debris in low-floor and lobby	- By distinguishing podium, high-rise and rooftop according to their functions, valuation of elevation type and performance
STR.	- Structure type, column spacing, number of members, and support type	- Strengthening earthquake-resistant seismic design - Ensuring adequate fire resistance structure	Evaluation of structural system and structure type Evaluation of sub structure settlement inside and outside building
MEP.	Air intake location& return system Screening for whether machinery, electric facilities and plumbing are resistant to blast and, seismic shock	- Ensuring emergency power - Separation arrangement of mechanical and electrical rooms from explosion hazard space - Enhancing facility performance in ECR	Check central equipment to reflect seismic resistant design Strengthening pipe and duct performance against explosive and seismic event
Fire & Egress	Fire protection system based on evaluation items reflecting government firefighting standards	- Firefighting facility compartment plan appropriateness - Strengthening of ventilation performance and preventing expansion of combustion - Evacuation safety zoning plan and design guideline	Strengthening fire- fighting system performance Evaluation of vertical and horizontal fire protection plan Safe zone and sunken space planning to enhance evacuation performance
SEC.	Security monitoring systems for internal and external bombs and biochemical terrorism and system efficiency	Security surveillance plan and facility protection plan considering anti-terrorism	- Security monitoring enhancement plan - CCTV installation plan and security guard arrangement

*ENV: Environment, ARC: Architecture, ENV: Envelope, STR: Structure, MEP: mechanical electrical and plumbing. SEC: Security

Table 4. Risk assessment of individual disaster scenarios and integrated disaster scenarios using the risk calculation formula

Individual Risk Calculation Formula		Integration Risk Calculation Formula	
$R_i = \sqrt[B_i]{C_i \times T_i \times V_i}$		$R = \propto \sqrt[n1]{\sum_{i=1}^{n2} R_i^{n1}}$	
Required value to calculate individual disaster scenarios		**Required value to calculate integrated disaster scenarios**	
R_i	Risk score of the i[th] disaster scenario	R	Aggregated risk
C_i	Consequences rating of the i[th] disaster scenario	R_i	Risk score of the i[th] disaster scenario
T_i	Threat rating of the i[th] disaster scenario	n2	Total number of disaster scenarios
V_i	Vulnerability rating of the i[th] disaster scenario	n1	Power value 10
βi	$β_i$ value depends on αi value αi =Min (Ci, Ti, Vi)/Max (Ci, Ti, Vi) If αi , βi=4.0, If αi, βi=3.0, If 0.1< αi <0.9, then βi =3.875 + 1.25* αi		Scaling factor 1/12

3.3 Composition of K-IDES

In this study, the concept of the quantitative evaluation of risk consists of three basic factors applied to the Risk Calculation Formula: Consequences, Threats, and Vulnerability. The high-level's category follows the FEMA IRVS rating classification system, but the details of the items and contents for the evaluation by item in lower level are derived by analysing domestic codes and design guidelines. Particularly, in this check list, the evaluation section related to the egress performance is newly built while reflecting design guidelines related to the evacuation zoning that are different from those in the US. Among the sub-evaluation items, items with similar purposes are grouped and detailed items are set up according to expert' advices in each field such as architectural design, structure, fire, disaster prevention, MEP, and security, and the factors severely affecting high-rise building are selected as weighted items by the same process. As Consequences, Threat, and nine categories of Vulnerability, K-IDES consists of 127 items, including 31 weighted items, and the related details of the items by disaster are determined by considering the direct effects against buildings according to disaster characteristics. Therefore, since correlation among disasters by detail items can not coincide, the total number of detail items and distribution ratio of them among C, T, and V by disaster are different and this inconsistency needs to be corrected in determining the C, T, and V values for risk assessment.

Table 5. K- IDES check list by category for risk assessment

Main evaluation items by category		Weighted item in main evaluation items	Manmade Hazards		Natural Hazards		Total No.
			B	F	S	W	
1. Consequence (Community loss after disaster)							
1.1. Local characteristics		Surrounding building density and land type`	3	3	3	3	3
1.2. Operation recovery		-	1	1	1	1	1
1.3. Physical loss		Asset value by building floor area multiplication office construction cost	1	1	1	1	1
Sum by category		2	5	5	5	5	5
2. Threats (Cause potential harm factors by disaster)							
2.1. Building characteristics		Resident population density	4	4	1	1	4
2.2. Environment index Wind frequency		Seismic frequency	1	1	3	3	6
Sum by category		3	5	5	4	4	10
3. Vulnerability (Physical feature in a building to exploitation or susceptible to hazard)							
3. 1 Site Plan	A. Road status around site	Distance between vehicle and elevation	3	-		-	3
	B. Road status in site	Space for entrance & activities of fire-fighting vehicles in emergency	4	4	4	-	4
	C. Access restriction to site	Vehicle entrance & exit solation level by visiting purpose	6	1	-	-	6
	Sum by category	3	13	5	4	-	13
3.2 Architecture Plan	A. Building shape	Height from ground	5	2	6	6	6
	B. Floor plan shape	Core placement type	1	1	2	2	2
	C. Internal space plan	Emergency exit plan's appropriateness	4	4	-	-	4
	D. Underground parking plan	Major facilities' locations & structure reinforcement degrees	3	2	-	-	3
	Sum by category	4	13	9	8	8	15
3.3 Envelope Plan	A. Podium window composition	Podium area glass specification	3	-	-	-	3
	B. High level window composition	High level area glass specification	-	3	3	3	3
	C. Envelope composition except window	Connection between building exterior and main structure	6	1	6	6	6
	D. Roof area configuration	Slope measurement up to bottom from pitch	-	-	1	2	2
	Sum by category	4	9	4	10	11	14
3.4 Structure Plan	A. Structure system	Lateral force resistance ability	3	2	2	3	3
	B. Structure type	Vertical irregularity	10	9	8	7	10
	C. Appendage structure type	Non-structural components in exterior	2	1	2	2	2
	Sum by category	3	15	12	12	12	15
3.5 MEP System Plan	A. Major component plan	Machine room proximity to high risk area	3	2	3	-	5
	B. Plumbing plan	System seismic design applicability	4	-	4	1	4
	C. Duct plan	-	1	-	1	-	1
	Sum by category	2	8	2	8	1	10

Main evaluation items by category		Weighted item in main evaluation items	Manmade Hazards		Natural Hazards		Total No.
			B	F	S	W	
3.6 Fire Protection Plan	A. Fire partition plan	Fire protection partition system application for vertical penetration part	3	3	3	-	3
	B. Firefighting equipment plan	Sprinkler Installation	4	4	4	-	4
	C. Smoke control plan	Vertical space (staircase, elevator, hallway) ventilation system	3	3	3	-	3
	Sum by category	3	10	10	10	0	10
3.7 Evacuation Plan	A. Horizontal evacuation plan	Separation distance between evacuation stairs for egress	5	5	5	-	5
	B. Vertical evacuation plan	Lifeboat conversion rate for emergency elevator	5	5	5	-	5
	C. Evacuation safety zone (Sunken plan)	Connection status check between escape safe area and special evacuation stairs	3	3	3	-	3
	Sum by category	3	13	13	13	0	13
3.8 Security Plan	A. Intra-building intrusion monitoring plan	Speed gate installation for visitor access control at lobby floor	3	3	-	-	3
	B. Threat monitoring plan	Installing a CCTV or sensor in the aisle allowing for outside accessing to buildings	3	3	-	-	3
	C. Out of building explosion threat monitoring plan	Security guard management plan to monitor threats and respond to emergencies	4	4	3	3	4
	Sum by category	3	10	10	3	3	10
3.9 Cyber Infra structure	A. Cyber security and emergency plan	Cyber security planning efficiency related to main equipment's operation	6	6	2	2	6
	Sum by category	1	6	6	2	2	6
Total vulnerability items sum		26	97	69	70	37	106
Total items sum (Consequence + Threats +Vulnerability)			107	79	79	46	127

* B: Blast, F: Fire, S: Seismic, Wind: Typhoon

4. SIMULATION

4.1 K-IDES Simulation plan for risk evaluation model review

It is necessary to apply the evaluation model to actual high - rise buildings for the applicability review of the weighted items and the weight distribution. The selection criterion for the simulation was set based on the items that can analyse the influence by items in the vulnerable part of the building while minimizing the group deviation on the environmental factors. In order to verify the distribution of the vulnerability of buildings with conditions similar to the regional characteristic related indicators of the risk assessment model, the selection of domestic high-rise buildings involves non-residential high-rise building with a height of 150m or higher in commercial districts with a floor area of at least 500% in Seoul, Incheon and Busan as a simulation sample. The following table describes the site's and building's characteristics of the main items selected for the simulation.

Table 6. Building information for K-IDES simulation

Building Information		A	B	C	D	E	F	G	H
Site	Location	Seoul	Seoul	Busan	Seoul	Seoul	Seoul	Seoul	Incheon
	Land type	GBD	GBD	GBD	GBD	GBD	GBD	GBD	CBD
	Usage	O, H, R, M	O, H, M	O, M	O, H, M	O, C	O, H, M	O, M	O, M, H
	FAR (%)	573	799	550	926	940	799	848	596
	Total bld. no. (Over 100m no.)	3 (1)	4 (3)	2 (1)	4 (4)	2 (1)	2 (2)	1 (1)	4 (2)
Bld.	Tower GFA (1000m2)	304	223	198	131	116	104	216	140
	Floor	123/B6	72/B8	63/B4	55/B7	50/B6	39/B8	23/B7	68/B3
	Height (m)	555	338	289	284	246	185	110	305
	Structure	SRC	SRC	SRC	SRC	SRC	RC	SRC	SRC

GBD: General Business District, CBD: Central Business District, O: Office, H: Hotel, R: Residential, M: Mall, C: Convention, SRC: Steel Reinforced Concrete, RC: Reinforced Concrete, FAR: Floor Area Ratio, GFA: Total Ground Floor AREA

4.2 Ratio allocation among C, T, and V and C, T, and V value decision by disaster

In order to select appropriate C, T, and V values for risk assessment, the first step is determining the ratio among C, T, and V by an expert interview and the ratio value (γ1) is set as the arithmetic average of experts' data except for the outliers. Next, since the ratio of the number of questions due to the difference in the number of evaluation items among C, T, and V is not consistent across disasters, the ratio average value (γ 2) of the number of items is calculated as the correction coefficient. The maximum values (γ 3) of C, T, and V for each disaster are calculated by dividing the values of Cγ1, Tγ1, and Vγ1 for each disaster by the ratio average value Mean γ 2 of Cγ 2, Tγ 2 and Vγ 2.

Table 7. Percentage allocation among C, T, and V and value assignments of C, T, and V by disaster

Allocation of Percentage	γ1: Percentage among C, T, V by disaster			γ 2: C, T, V percentage of questions by disaster			γ3: γ1/ Mean (γ 2) by C, T, V		
	Cγ1(%)	Tγ1(%)	Vγ1(%)	Cγ 2(%)	Tγ 2(%)	Vγ 2(%)	Cγ 3	Tγ 3	Vγ 3
Blast	24	30	46	4 .7	4.7	90.7	3.40	4.85	0.53
Fire	21	28	51	6.3	6.3	87.3	2.98	4.52	0.59
Seismic	18	27	55	6.3	5.1	88.6	2.55	4.36	0.63
Wind	17	25	58	10.9	8.7	80.4	2.41	4.04	0.67
Mean γ 2	-	-	-	7.1	6.2	86.8	-	-	-

4.3 Integration risk result

Based on the maximum value (γ 3) of C, T, and V for each disaster, the selection value of the detail item is determined by the isometric ratio among the five intervals. The weighted items are allocated among values ranging from 1.14 to 3.75 based on the importance of each item and the highest number of weighted items by the second level category in the expert groups' interview results. Due to the fact that the factors from site to evacuation in vulnerability are influenced by the disaster's characteristics, the distribution of the items is interlinked, in the case of terrorism and typhoon, the difference of values' sum range by Consequence, Threats, and Vulnerability occurs from 2.03 to 4.34 times. Therefore, it is expected that an individual risk assessment's result by disaster cannot exert an equal effect when the final integrated risk assessment is output.

Table 8. C, T, and V value attributes by disaster and weighted items value assignment for risk assessment

C, T, V values by disaster		Attribute options					Weighted items		Value sum range	
		a	b	c	d	e	No.	Value range	Min	Max
Blast	Cb	0.68	1.36	2.04	2.72	3.40	2	1.86~2.97	10.96	54.81
	Tb	0.97	1.94	2.91	3.88	4.85	1	1.82	11.10	55.52
	Vb	0.11	0.21	0.32	0.42	0.53	24	1.14~3.75	13.04	64.94
Fire	Cf	0.97	1.94	2.91	3.88	4.85	2	1.86~2.97	5.16	25.99
	Tf	0.90	1.81	2.71	3.62	4.52	1	1.82	7.51	37.51
	Vf	0.12	0.24	0.35	0.47	0.59	18	1.77~3.75	11.27	56.16
Seismic	Cs	0.51	1.02	1.53	2.04	2.55	2	1.86~2.97	5.99	29.98
	Ts	0.87	1.74	2.62	3.49	4.36	2	1.63~1.82	4.52	22.61
	Vs	0.13	0.25	0.38	0.51	0.63	15	1.30~3.75	12.25	61.07
Wind	Cw	0.48	0.96	1.45	1.93	2.41	2	1.86~2.97	3.31	16.56
	Tw	0.81	1.62	2.42	3.23	4.04	1	1.82	2.55	12.77
	Vw	0.13	0.27	0.40	0.53	0.67	7	1.30~3.75	6.88	31.87

4.4 Test result Analysis

By using the K-IDES checklist with the application of the derived C, T, and V values by the disasters, eight buildings of the same type of high-rise complex buildings in three cities are evaluated for integrated risk assessment and the evaluated results range from 63.5% to 75.4%. There are sampled among buildings of a similar architectural type, but the deviation among results shows considerable differences in the Threats by disaster, which are attributed to the regional variation caused by site characteristics and the different natural environment factors. Regarding explosive terror, the risk of blast increases because of the high rate of reflection of potential threats due to regional characteristics and site characteristics. Regarding fire, it has disaster characteristics similar to those of explosive terror, but it is the most likely to occur among all disasters, so in the evaluation of fire's risk, it gives importance to the threats of asset loss at dense city, and the resulting variation of individual disaster risk assessment is the largest even among similar buildings. Regarding earthquakes, the presence of the seismic zone, which is a threat factor, and the physical durability against seismic in vulnerability are important in risk assessment. In particular, it shows a deviation between buildings according to reflection of the seismic design in the factors of architecture, elevation, structure and MEP. Regarding typhoon, the influence of vulnerability factors such as the type of building and the composition of the building envelope, and the coefficient of wind quantity in threat element, are important. But as the evaluation result of the individual disaster risk assessment, eight samples belonging to high-rise office buildings with similar architectural types, and six buildings are located in the same city, so the standard deviation among the samples is reduced and the impact on the integrated risk is diminished since the typhoon's question quantity is at a rate of 50% compared to the other disasters' questions. As a result, the integrated risk of building H located in Incheon records the highest, and building G is located in Seoul, which means that its height is lower than the others, the shape is relatively simple, the function in building usage is not complicated, and the location and surrounding characteristics as compared with the other sites are evaluated as comparatively less risky, is evaluated to be the most safe building among the listed buildings.

Table 9. Risk assessment result by simulation building

Category	Req. Index	Simulation Buildings								Mean	S. D
		A	B	C	D	E	F	G	H		
Blast	Cb	17.82	19.19	15.97	17.33	15.39	15.29	15.29	19.36	16.96	1.60
	Tb	22.65	17.62	16.60	19.76	13.30	13.48	10.56	18.41	16.55	3.67
	Vb	31.50	33.15	32.24	31.61	35.51	31.85	29.08	37.98	32.86	2.56
	αt	0.57	0.53	0.50	0.55	0.37	0.42	0.36	0.48	0.47	0.07
	βt	4.58	4.54	4.49	4.56	4.34	4.40	4.33	4.48	4.47	0.09
	Rt	7.87	7.80	7.50	7.67	7.75	7.36	7.05	8.36	7.67	0.36
Fire	Cf	25.38	27.31	22.74	24.68	21.91	21.77	21.77	27.56	24.14	2.28
	Tf	20.90	17.28	15.96	20.16	13.24	12.34	10.69	17.77	16.04	3.45
	Vf	24.97	27.98	28.13	26.27	29.63	26.87	23.82	32.21	27.49	2.48
	αf	0.82	0.62	0.57	0.77	0.45	0.46	0.45	0.55	0.59	0.14
	βf	4.90	4.65	4.58	4.83	4.43	4.45	4.44	4.56	4.61	0.17
	Rf	6.93	7.70	7.49	7.10	7.72	7.37	6.98	8.31	7.45	0.43
Seismic	Cs	13.37	14.39	11.98	13.00	11.54	11.47	11.47	14.52	12.72	1.20
	Ts	15.69	17.82	14.55	8.63	8.33	15.87	8.63	8.63	12.27	3.81
	Vs	25.40	28.53	27.10	27.78	29.36	26.63	25.04	33.37	27.90	2.48
	αs	0.53	0.50	0.44	0.31	0.28	0.43	0.34	0.26	0.39	0.10
	βs	4.53	4.51	4.43	4.26	4.34	4.41	4.31	4.20	4.36	0.12
	Rs	6.64	7.21	6.76	6.60	6.54	6.84	6.14	7.29	6.75	0.34
Wind	Cw	12.63	13.59	11.31	12.28	11.38	10.83	10.83	13.71	12.07	1.09
	Tw	13.00	13.00	12.63	11.53	8.59	8.59	7.12	10.21	10.59	2.15
	Vw	14.84	16.43	14.10	14.68	14.90	14.59	15.49	16.37	15.18	0.79
	αw	0.85	0.79	0.80	0.79	0.58	0.59	0.46	0.62	0.68	0.13
	βw	4.94	4.86	4.88	4.86	4.60	4.61	4.45	4.65	4.73	0.16
	Rw	4.85	5.15	4.76	4.82	4.88	4.78	4.92	5.27	4.93	0.17
R total (%)		68.13	70.80	68.06	67.37	69.71	67.22	63.53	75.39	68.78	3.19

5. CONCLUSION

The purpose of this study was to establish a classification system for the evaluation of risk elements in Korean high-rise buildings, excluding legal standards. Another purpose was to analyze and verify the results of the simulation application of the proposed program by developing numerical measurements for risk evaluation and methodology of risk evaluation. To verify the applicability of the K-IDES, high-rise buildings over 100 m in three cities and with a construction time of under 10 years, with different environmental indicators, were selected. The evaluation results derived from the simulations using the IRVS and K-IDES were compared. This study embodies the evaluation method for the elements except for the legal standards established based on preliminary studies and establishes an evaluation element classification system and the criteria of evaluation items and in order to verify it, the simulation and evaluation results are analyzed by collecting simulation buildings' data and interviewing the experts who designed them. In order to certifying the sensitivity of K-IDES, the high-rise office buildings with similar condition sites and architectural form are selected as the analysis targets and the result has comparable variation within the range of 11.9%. Regarding the limitations of this study, first, it was difficult to assess the application to different types of buildings by interpreting the evaluation results due to the restriction of architectural types. Second, since the purpose of this study was to develop an evaluation model to screen whole buildings and not a particular section of buildings, there was a limitation in deriving the hazardous areas related to the architectural design elements by allocating the same weights of scores among vulnerability's categories without considering the correlation with dangerous architectural parts according to disaster characteristics. Third, in the case of evaluation items that reflect the building performance criteria, as the standards for domestic design guidelines are insufficient, evaluation items that are difficult to apply quantitative analysis criteria are included in the evaluation items, which hinders the accuracy of evaluation results. Therefore, future research should continuously verify the results and analysis methods on the risk assessment of domestic buildings through the expansion of the buildings' type and the diversification of the geographical location and as the analysis method, it will allocate the proportion of C, T and V while reflecting the weight by disaster and until the scope of statistical analysis, the selection of weighted item and weighting in the analysis method by expanding the experts' interview in the specialized group will be conducted in order to increase its reliability and precision. In addition, the complementary research on the direction of establishing the detailed standards for evaluation items that are difficult to quantitatively analyze due to insufficient standards in the design guidelines will be required. The final goal of the research is to build an integrated system to assess risk in a building against disasters by checking for vulnerable areas from the beginning of design and using risk management after constructing the building. By developing the method of continuous data scaling and systematic management for buildings, it is expected that this study will contribute to risk management against complex disaster by extending to various infrastructures and other types of buildings.

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