

# A Study on Improvement Plans of Earthquake Disaster Safety Management in National Industrial Complexes

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## **Abstract:**

The purpose of this study is to identify the problems of the earthquake disaster safety management in the national industrial complexes and to suggest improvement measures. Literature review for the safety management system of the Korea Industrial Complex Corporation and interview with practitioners was conducted. and Seismic design application survey was conducted on 28 national industrial complexes. In order to improve Earthquake Disaster Safety Management, five measures were suggested such as the reinforcement of laws and regulations related Seismic. It is expected that the improvement measures presented in this study can be used as policy-making data for improving the seismic performance of the national industrial complexes in the future.

**Key Word:** National Industrial Complexes; Earthquake Disaster; Seismic Design; Safety Management.

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## I. Introduction

### Background

Recently, massive earthquakes have occurred frequently around the world, including China and Japan, which are neighboring countries of South Korea. In South Korea, the initial seismic design concept was introduced by revising the Building Act in 1988 to ensure safety against earthquakes. In 2008, the Earthquake and Volcanic Accident Countermeasures Act was enacted to protect people's lives, property and major facilities from disasters caused by earthquakes, tsunami, and volcanic activities, thereby expanding the scope of facilities reinforcement, support plans and seismic design obligations. However, the earthquake in Gyeongju in 2016 with magnitude 5.8 and the earthquake in Pohang in 2017 with magnitude 5.4 ranked first and second in scale since 1978 (Ministry of Public Administration and Security, 2019). This led to the re-recognition of the need for efficient and systematic management of earthquake disasters, breaking away from existing perception of earthquake safety zones.

In particular, the production scale of industrial complexes strategically developed for the purpose of developing national and regional cracks and improving industrial competitiveness totaled 985 trillion won (South Korean currency, ₩). Industrial complexes account for 68.5percent (%) and 73.6(%) of the nation's manufacturing output and exports, respectively, playing a pivotal role in the domestic economy and industry (Korea Industrial Complex Corporation, 2016). In an earthquake occurrence, it is concerned that there will not only be casualties but also huge losses to the national economy. Accordingly, the South Korea Industrial Complex Corporation, which is responsible for managing and supporting industrial complexes, is designated as a disaster management agency to conduct safety guidance and inspection. However, it is difficult to systematically manage earthquake disasters due to overlapping of management entities by related statues, unclear director, and insufficient management of the seismic design database for facilities in industrial complexes.

The main previous studies related to industrial complexes and seismic disaster are as follows. Risk assessment was carried out considering the effect of earthquakes and domino effects when large-scale LNG storage facilities were constructed (Koo, 2017). The seismic hazard level of the Ulsan petrochemical complex was assessed using the seismic wave generation program (Kim, 2008). In addition, a survey companies operating in the Gumi National Industrial Complex suggested measures to promote the upgrading of the structure (Yang, 2015). The study proposed that efficient improvement of the method of sale was proposed to enterprises operating in the 4th General Industrial Complex in Cheonan by compiling the matters to be considered in the decision to move in and the results of the analysis of domestic and foreign industrial complexes (Ko, 2009). Major linear studies are conducted in a limited way with studies related to the assessment of earthquake risk in some industrial complexes, the upgrading of industrial complexes and the improvement of the sale rate. In addition, research is required to deduce problems related to the current safety

management of seismic disaster in industrial complexes and to suggest way to improve them. Therefore, the study aims to examine the operation status of the South Korea Industrial Complex Corporation's safety management in national industrial complexes. Also, the study aims to identify the problems in safety management of earthquake disasters and to present measures to improve them through investigation of seismic design application status. The objectives of this study are as follows: First, to conduct a survey on the application of seismic-resistant design to 28 national industrial complexes in the Korea Industrial Complex Corporation conducts and to investigate the problems of seismic disaster safety management in national industrial complexes. Second, to present improvement measured by compiling the investigated problems of seismic disaster safety management in the national industrial complex.

### **Method and Scope of the Study**

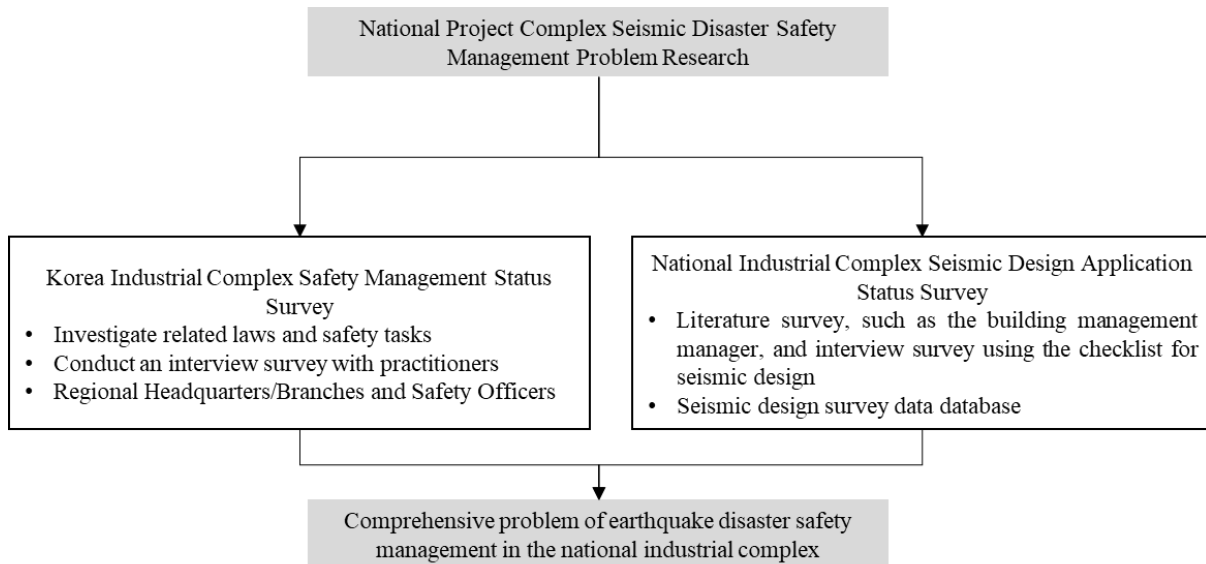
This study conducted a survey on the safety management operation system and interview of the Korea Industrial Complex Corporation, the main body of the management of the industrial complex, to identify and improve the safety management problems of the national industrial complex. The study conducted a survey of 28 national industrial complexes on the government's application of seismic design and integrated and rearranged current safety management problems in national industrial complexes. Subsequently, improvement measures are presented by reflecting relevant literature surveys and expert opinions. The detail description of the research procedures and methods outlined above is as follows: First, the aim, scope and procedure of this research are established by considering the policies and prior studies related to the safety management of earthquake disasters in national industrial complexes. Second, conduct a survey on the status of safety related to the Korea Industrial Complex Corporation, the main body of the National Industrial Complex. Subsequently, an interview survey is conducted with office director of safety at the industrial complex and the workplace to investigate problems in safety management of seismic disasters. Third, a database of seismic design application data will be established in 28 national industrial complexes by utilizing a survey table on seismic design application, along with literature review including building management registration. Also, the study investigates seismic disaster safety management problems in the database construction process. Lastly, the problems identified in the above process are integrated and rearranged to reflect the opinions of experts, and the measures for improving the safety management of earthquake and disaster in the national industrial complex are presented in consideration of previous research and expert opinions.

## **II. Investigation on Safety Management of Seismic Disaster in National Industrial Complexes**

### **Procedure and Method**

There is a high risk of massive casualties and economic losses in the event of a seismic disaster, due to the nature of the industrial complex where complex facilities are created in a group for the purpose of developing national and regional cracks and improving industrial competitiveness. The investigation of the problems of the current seismic disaster safety management in the national industrial complex should be preceded in order to minimize these damages and to prepare an efficient management system. To achieve the aim, a survey was conducted on the current status of safety management and application of seismic design by the Korea Industrial Complex Corporation, the operator of the national industrial complex. Detailed description of the procedures and methods for investigating the national seismic disaster safety management problems is as follows (See figure 1).

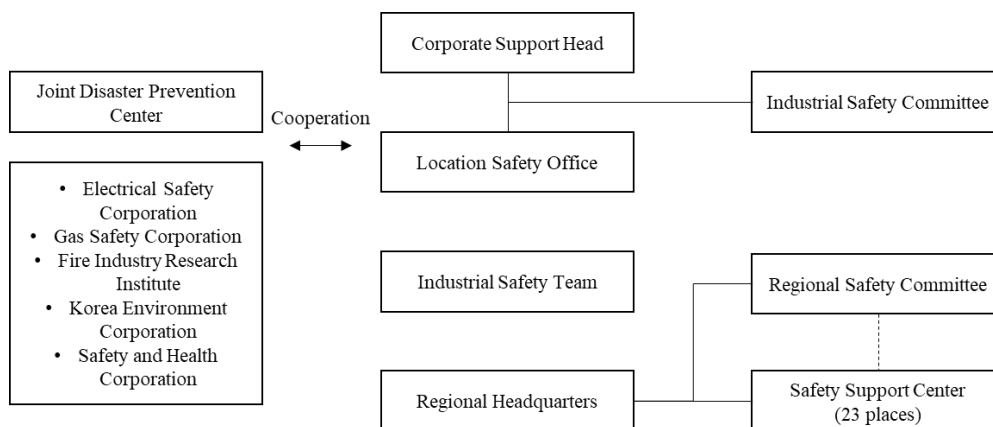
First, the Korean Industrial Complex Corporation, as the managing body of the National Industrial Complex, conducts a literature review on the laws, guidelines, and the status of major tasks. Based on this, interview in-person will be conducted with office director of safety of the Korea Industrial Complex Corporation and occupied companies to investigate current problems in safety management of seismic disasters. Second, a database on the application of seismic design in national industrial complexes is established through a written survey using a literature survey, such as a building management registration, and an seismic-resistant status survey table. Then, determine the application status of seismic design in the national industrial complex and the problems identified during the investigation process. Third, the problems investigated in the above process are integrated and rearranged by reflecting the opinions of experts' opinions. It will then be used as basic data to present measures to improve the safety management of earthquake and disaster in national industrial complexes.



**Figure no 1:** Procedures and methods for investigation seismic disaster safety management problems.

### Status and Interview Survey

It is required in order to identify problems in the safety management of the national industrial complex by understanding the safety management system of the Korea Industrial Complex Corporation, as the managing body of the national industrial complex. Therefore, the Korea Industrial Complex Corporation investigated the legal basis for safety, the human resources management systems and the details of major tasks. The Korea Industrial Complex Corporation is related to the following Laws and Acts: Article 3 of the "Framework Act on the Management of Disaster and Safety and Enforcement Decree of the Same Act" (Disaster Management Responsible Agency); Article 25-2 of the "Framework Act on the Management of Disasters and Safety" (Disaster Prevention Measures by the Head of the Disaster Management Agency); Article 45 of the "Industrial Cluster Development and Factory Establishment Act and Article and of the Enforcement Decree of the Same Act" (Safety Management of Industrial Complexes); Safety Management Status of Article 16 of the "Industrial Complex Management Guidelines (Guidelines for Safety Management)". The main jurisdictions are 32 national industrial complexes, 13 general industrial complexes, 14 foreign-invested area and two agricultural and industrial complexes. In addition, a location safety office is established with the head of the Corporate Support Headquarters, and a cooperative relationship with the relevant Disaster Prevention Center is maintained, and a safety management operation system is organized as follows (Figure no2);



**Figure no 2:** Industrial Complex Corporation Safety Management Operating system.

The Korea Industrial Complex Corporation, established with the aim of developing and managing industrial complexes and supporting industrial activities of enterprises, manages a total of 61 industrial complexes, including 32 national industrial complexes. It is designated as a disaster management agency under the Framework Act on Disaster and Safety Management. Therefore, the organization should perform duties such as establishing a disaster prevention management system for the facilities under directors' jurisdiction and promoting safety-related activities. In addition, in accordance with the Act on the Promotion of Industrial

Aggregation and Factory Establishment and related guidelines preventive activities such as safety inspection, guidance, safety education, and campaigns are carried out in cooperation with safety-specialized institutions including fire stations, Korea Occupational Safety and Health Agency and relevant ministries.

The company is carrying out tasks such as radio waves and restoration support to related agencies in the event of a disaster or accident, including an earthquake. These tasks are handled by the location safety office in the industrial complex and by each regional headquarters and branch office including Safety Support Center. The safety Committee is operated to review and provide advice on the overall safety management of industrial complexes in preparation for the occurrence of multiple accidents in industrial complexes. In addition, the head of the Corporate Support Headquarters is comprised of about 15 experts, led by the chairperson, to conduct related advisory activities, such as deliberation on the establishment of a comprehensive plan for safety management, and improvement of policies and systems.

In this study, based on the results of the survey on the scope and system of the Korea Industrial Complex Corporation, the operator of the National industrial complex, an interview survey was conducted with the regional headquarters, branch offices and official safety management personnel of the occupied companies to identify the current problems in the safety management of the seismic disaster. Table no1 is summarized as follows;

**Table no 1:** Overview of the interview survey of the officials in charge of safety management of South Korea.

Classification	Details
Period	- 2017.10. ~ 2017.12.
Subject	- Korea Industrial Complex Corporation Regional Headquarters / Designated person in charge of safety with 23 branches - Designated person in charge of 17 branches registered companies (Intensive management of facilities)
Contents	- Inspection of implementation of disaster safety management - Safety inspection by facility and business establishment

This study was conducted by visiting the local headquarters/branch offices of the Korea Industrial Complex Corporation and working-level officials of the occupied companies to conduct an interview survey on the implementation of earthquake and disaster safety management, and the problems identified are as follows:

**1) Lack of legal basis for safety examination and reduced efficiency of inspection**

The Korea Industrial Complex Corporation is designated as a disaster management agency under Article 3 of the Framework Act on the Management of Disaster and Safety, but it has no legal force in relation to safety management. Also, only safety guidance authority shall be granted under Article 45 of the Industrial Cluster Development and Factory Establishment Act and Article 58 of the Enforcement Decree of the same Act, and the head of the administrative agency shall be request to cooperate in the corrective action during the safety guidance. The safety management work of various facilities and sites in the industrial complex may result in blind spots of management as it is carried out in accordance with the applicable laws of each department as follows (Table no2). In addition, guidance inspections are conducted at the same workplace more than 10 times a year, causing a burden on the workplace, and the work efficiency is reduced due to the ambiguity of the competent department that can manage them in an integrating.

**Table no2:** Status of safety management agencies by sector.

Classification	Relevant legislation	Main task	Organization in charge	Relevant department
Safety education/industrial accidents	Industrial Safety and Health Act	Work environment and disaster inspection	Safety and Health Agency	Ministry of Employment and Labor
Gas safety	High Pressure Gas Safety Control Act	Safety of high-pressure gas	Gas safety Corp.	Ministry of industry
Electrical safety	Electrical Business Act	Safety inspection of electrical equipment	Electrical safety Corp.	Ministry of industry

Fire safety	Installation and Maintenance of Fire-Fighting System Act	Fire-fighting facility safety inspection	Fire station	Ministry of public administration and security
Handling dangerous goods	Dangerous Goods Safety Control Act	Dangerous goods storage	Fire station	Ministry of public administration and security
Hazardous chemicals	Chemical Control Act	Toxic/hazardous chemicals	Regional environmental office, environmental research institute	Ministry of environment
Pipeline safety	Oil Pipelines Safety Management Act	Pipeline safety management	Korea gas safety corp. local government	Ministry of industry
Natural disaster	Natural Disaster Countermeasures Act	Natural disaster	a local government	Ministry of public administration and security

**2) Limitation of securing safety-related resources against seismic disasters**

Large companies are preparing for future earthquakes and other disaster by setting up their own safety management plans, such as hiring safety management personnel, evaluating annual seismic performance, and establishing reinforcement plans by compiling a separate safety-related budget. However, in the case of medium and small companies, inspection of hazardous facilities and seismic performance evaluation in the workplace have not been carried out periodically due to limitations in securing budget. It is also aware of the need for proper repair and reinforcement of some hazardous facilities, but only short-term repair work is carried out due to insufficient funds.

**3) Shortage of safety guidance and inspection personnel**

The Korea Industrial Complex Corporation is conducting safety guidance and inspection of vulnerable areas and safety conditions in the complex, focusing on vulnerable times such as winter and thawing seasons. As the number of companies in charge of safety management in the Korea Industrial Complex Corporation is excessive (as of 2017, 19,703 registrated companies), there is a concern that formal safety guidance and inspection will be conducted as work fatigue increases.

**4) Shortage of promotion on expertise in the seismic disaster safety**

Specialization is required through training in accordance with systematic education programs in order for each subject to respond relevantly and swiftly in a disaster situation. In most cases, safety managers in the Korea Industrial Complex Corporation are performing both resident management tasks and duties, and they are focusing on tasks related to the management of registered companies and structural advancement. It is difficult to secure disaster management capabilities for safety managers at the Korea Industrial Complex Corporation, as disaster safety education is also operated mainly by external institutions. In addition, the safety managers of the industrial complex and the registered tenant companies lack expertise as they perform concurrent duties other than hiring safety managers or entrust them to external companies if necessary.

**Investigation on the application of seismic design to National Industrial Complexes**

The Building Act and the Earthquake and Volcanic Accident Countermeasures Act were enacted to prevent seismic damage and minimize damage in the earthquake occurrence, and the seismic design standards were prepared and applied. Facilities in national industrial complexes are also required to be seismic-resistant in accordance with relevant laws. In order to identify current problems in the safety management of seismic disaster in national industrial complexes, a survey of the application status of seismic design in national industrial complexes was conducted as follows (Table no3).

**Table no3:** A survey on the seismic design of national industrial complex.

Classification	Details
Period	- 2017.05. ~ 2017.12.
Subject	- 28 national industrial complexes nationwide (excluding Daegu, Pohang Blue valley, Bitgreen and Jangseong) - 19,703 companies / 41,914 units under the jurisdiction

Contents	☞ Research on literature (Building management register, seismic design verification) ☞ Interviews and written surveys of occupied companies (using the earthquake-resistant survey table)
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As shown in Table no4, literature surveys, including building management registrations, are conducted on the tenant companies in 28 national industrial complexes nationwide. If necessary, a visit and a written survey were conducted to the official staff of the occupant enterprise using the seismic status survey table as follows (Figure no3).

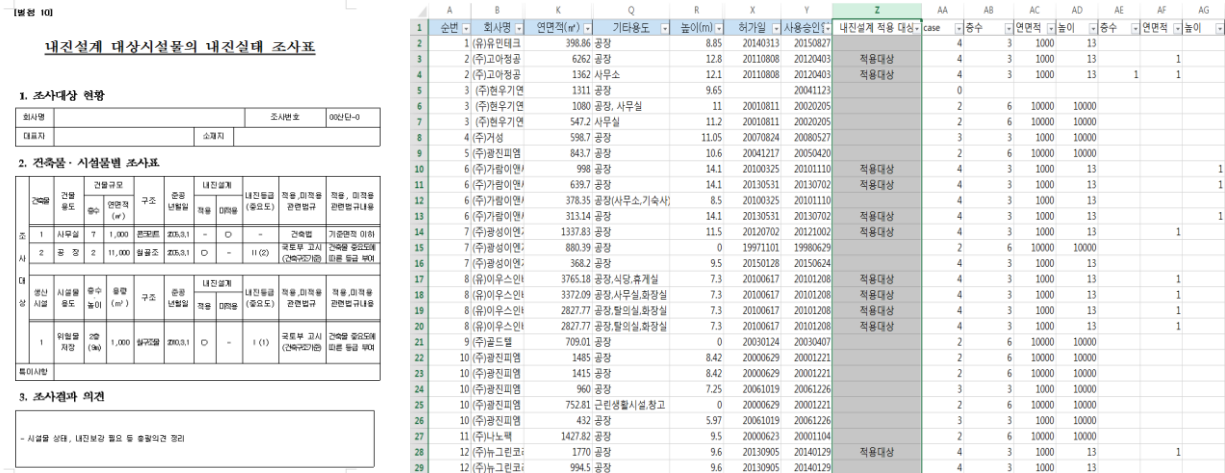


Figure no3: Establishment of a survey table and database on the application of seismic design in national industrial complex.

As shown in Figure no 2, the results of an annual survey on the application status of seismic design in national industrial complexes based on the database of seismic design in national industrial complexes are as follows (Table no 4). The survey items were used to build database including ground area, building permit date and seismic design application status. The seismic design standard applied according to the purpose and timing of the national industrial complex are different in the course of the investigation into the seismic design of the national industrial complex. Therefore, the seismic design application was determining based on the seismic design criteria at the time of building permit not the current seismic design criteria.

Table no4: A survey on the application of seismic design to national industrial complexes by years.

Classification	Total area [㎡]	Seismic design applied area [㎡]	Rate of seismic resistance [%]
~ 1979	4,706,452	-	0.0
1980~1989	10,859,010	480,704	4.4
1990~1999	18,088,014	3,660,418	20.2
2000~2009	28,421,857	17,979,067	63.3
2010 ~	10,995,355	9,684,202	88.1
Unknown	4,539,857	-	0.0
Total	77,610,545	31,804,391	41.0

As shown in Table no5, the results of an annual survey on the application of seismic-resistant design to national industrial complexes are summarized. Since the establishment of the national industrial complex, the seismic-resistant rate has been continuously increasing, and 88.1% of the national industrial complex has been found to have been the highest since 2010. This is considered to have had a significant impact on the seismic-resistant rate of national industrial complexes as the scope of th mandatory application of seismic design has

gradually expanded since 1988 when seismic design standards were first established due to the revision of the Building Act. In order to investigate the application status of seismic design according to the use of facilities constructed in national industrial complexes, Table no5 was reorganized according to the classification of building use under Article 3-5 of the Enforcement Decree of the Building Act.

**Table no5:** Results of survey on the application of seismic design to national industrial complex by building use.

Classification	Total area [m <sup>2</sup> ]	Seismic design applied area [m <sup>2</sup> ]	Rate of seismic resistance [%]	Classification	Total area [m <sup>2</sup> ]	Seismic design applied area [m <sup>2</sup> ]	Rate of seismic resistance [%]
Detached dwelling	56,434	52,775	93.5	Factory	74,734,703	30,670,795	41.0
multi-unit dwelling	343,861	145,599	42.3	Warehouse facility	917,858	381,860	41.6
1st class neighborhood living facility	50,889	18,300	36.0	Dangerous goods storage and treatment facility	393,507	177,215	45.0
2nd class neighborhood living facility	162,592	10,997	6.8	automobile-related facility	71,614	6,725	9.4
Cultural and assembly facility	5,277	4,749	90.0	animals and plants-related facility	102	-	-
Religious facility	-	-	-	Resource circulation-related facility	23,375	4,432	19.0
Sales facility	60,979	59,970	98.3	Correctional and military facility	379	-	-
Transportation facility	23,578	10,529	44.7	Broadcasting and communications facility	31	-	-
Medical facilities	21,189	21,189	100	Cemetery-related facility	-	-	-
Educational research and welfare facility	256,527	90,897	35.4	Power generation facility	665	-	-
The elderly facility	10,442	-	-	Tourism resting facility	12	-	-
Training facility	-	-	-	Funeral facility	-	-	-
Excercise facility	522	-	-	Campsite facility	-	-	-
Business facility	438,276	131,287	30.0	Unclassified classification	20,663	-	-
Accommodation facility	17,072	17,072	100	Total	77,610,545	31,804,391	41.0
Recreational facility	-	-	-				

As a result of the survey on the application of seismic design to national industrial complexes by building use, the total number of building is classified into 29 categories. The contribution of national industrial complexes to the national economy has a significant impact on 56.04% of the total output of industrial complexes (Korea Industrial Complex Corporation, 2016). In particular, 96.3% of the total ground area of factories used for manufacturing purposes was found to account for the highest percentage, and facilities such as religion and training were found to have been established. The ratio of the area to which the seismic design was applied, such as the seismic rate, was found to be 41.0%, which was the same as the seismic rate of the factory facility.

The ratio of the total ground space used for sales and accommodations is 4.7%, which is relatively small compared to the total floor area of factory facilities, which is believed to have little impact on the seismic-

resistant rate of the national industrial complex. Therefore, in order to improve the seismic resistance rate of the national industrial complex, seismic performance evaluation of various facilities in the factor use should be conducted first, and reinforcement measures are required if necessary. As shown, the safety management system for seismic disasters generated in the course of conducting a survey on this application of seismic design in national industrial complexes is summarized as follows:

First, structures other than buildings, such as storage tanks, pipes and equipment, are subject to reporting, not subject to approval or permission under the Building Act. Therefore, it is difficult to investigate the installation of structures and violations in the complex due to limited safety personnel of the Korea Industrial Complex Corporation, and there is a limit to relying on the reported contents of the building owners and tenant companies. In addition, it is difficult to secure accurate data due to the disposal and insufficient storage of documents prior to 2005 when the registration of computerized management of official reports was implemented. For these reason, the application status of the seismic design of the workpiece was excluded from this study, and a supplementary study is required.

Second, there is a limit to the verification when the seismic design standards are applied at the time of design or when the tenant company perform its own seismic reinforcement work as data base are collected based on the building management register. In addition, it is difficult to collect appropriate data because there is no legal obligation to provide the relevant information as it corresponds to the internal information of the entity.

Third, it is difficult to establish an accurate database of seismic design application due to the different management entities depending on the types of older materials such as gas and oil, and the lack of integrated systems and standards to systematically manage them.

Fourth, a survey on the application of seismic design in national industrial complexes is conducted based on the building management register prepared according to the seismic design standards prescribed by the Building Act at the time of building permit. Thus, it is difficult to confirm the actual seismic performance when applying the current seismic design standards, and a separate seismic detailed capability evaluation is required.

### **III. Proposal of improvement plan for safety management of seismic disaster Comprehensive seismic disaster safety management problems and selection of improvement measures**

In the previous chapter, problems were investigated in the process of investigating the status of safety management and interview with working-level officials of the Korea Industrial Complex Corporation, as the managing body of the national industrial complex. In chapter 2.2, problems were investigated in the process of investigating the application of seismic design in the national industrial complex as follow (Table 6).

**Table no6:** The results of investigation on the problems of seismic disaster safety management in the national industrial complex

Problems of Safety Management in Korea Industrial Complex Corporation	Problems of the actual condition of seismic design in National Industrial Complexes
Lack of legal regulations (i.g. safety inspections of the industrial complex) Safety inspection and guidance limits according to the application of individual law Insufficient establishment of an integrated management system and reduced work efficiency Limits on securing safety-related funds Lack of safety experts in the industrial complex and tenant companies Lack of safety inspection and guidance expertise Lack of education and training programs	Limitations of investigation on application of seismic design of work-pieces Insufficient management of documents related to seismic design application Insufficient sharing of information related to seismic design Lack of an integrated earthquake-related database Limits to check whether the existing facilities have secured seismic performance due to strengthened seismic design standards

As shown in Table no7, the problems of seismic disaster safety management in national industrial complexes were re-classified into the same type of problems, reflecting the opinions of relevant experts, including working-level officials of the Korea Industrial Complex Corporation. This study complied a total of five categories of subdivision surrender and derived detailed plans for each items as follows (Table no7), and presented the detailed plans for improving the safety management of seismic disasters in national industrial complexes, including domestic and foreign policy data, as well as expert opinions.

**Table no7:** Comprehensive plan for improving the safety management of seismic disaster in National Industrial Complex

Classification	Details
Strengthen legal regulations related to seismic-resistant disasters	<ul style="list-style-type: none"> <li>• Strengthen regulations related to seismic-resistant materials in the industrial complexes</li> <li>• Granting authority to make measures to remove and destroy seismic-gr</li> </ul>



	ade hazardous facilities if left unattended
Maintenance of the safety management system for industrial complexes	<ul style="list-style-type: none"> <li>• Securing the authority to request information from companies that move into seismic-grade hazardous facilities</li> <li>• Securing access rights for guidance purpose of occupied companies</li> <li>• Sharing information with local governments and management agencies and securing the right to disclose, the authority to execute measures for demolition and destruction is given.</li> </ul>
Establishment of support system for seismic enforcement of occupied companies	<ul style="list-style-type: none"> <li>• Fund for support of seismic retrofit in industrial complexes</li> <li>• Introduction of an incentive system for seismic reinforcement</li> <li>• - Introduction of seismic hazard designation system</li> </ul>
Development of seismic inspection support tools	<ul style="list-style-type: none"> <li>• Development of seismic inspection manual for factor structures</li> <li>• Development of seismic hazard maps for industrial complexes</li> <li>• Development and establishment of a seismic-related DB and seismic design self-inspection system</li> </ul>
Strengthen education and promotion of seismic reinforcement	<ul style="list-style-type: none"> <li>• Establish a road-map for education and promotion related to seismic reinforcement of occupied companies</li> </ul>

**Proposal of improvement plan for safety management of seismic disaster**

Detailed measures for each item on the improvement of the national industrial complex seismic disaster safety management shall be as follows:

**1) Consolidate legal regulations related to earthquakes**

Under the Framework Act on Disaster and Safety Management, the Korea Industrial Complex Corporation is designated as a disaster management agency. However, there is no legal force in relation to safety management, and the Industrial Aggregation Act only grants the authority to safety guidance. However, it deals with dangerous substances and chemicals in industrial complexes, which are expected to cause massive damage in the event of earthquake. Thus, it is necessary to reinforce seismic-regulation on important facilities in national industrial complexes as well as public facilities through the revision of the Building Act and Special Act on Safety and Maintenance of Facilities, which are compulsory for the safety management of facilities.

In other words, when seismic design application facilities are completed for a certain period of time after construction, seismic performance evaluation is mandatory, and the results of the evaluation are data-based and managed by the Korea Industrial Complex Corporation which is body of management. In this case, if the results of the seismic performance evaluation do not meet the seismic performance, the seismic reinforcement work shall be prescribed to be carried out within a certain period of time, and the suspension of work and access control shall be allowed only after the period passes. However, the support system that can alleviate the economic burden should also be considered, regarding the situation in which it is difficult to assess seismic-resistant performance and meet the cost of reinforcement. In addition, if a facility exposed to the risk of collapse, is left unattended due to the economic situation of the tenant company as a result of safety inspection and seismic performance evaluation, the Korea Industrial Complex Corporation shall only recommend the removal and destruction measures to the relevant company and shall not enforce them. Therefore, it is necessary to prepare a regulatory framework to eliminate risk factors in advance.

**2) Maintenance of the safety and management system**

Although the Act on Industrial Cluster Development and Factory Establishment stipulates the performance of safety guidance in the industrial complex, it is required to be reorganized as it focuses on the role of supporting safety management work in cooperation with safety agencies and administrative departments. First, it is required to secure the right to request information from tenant companies. As confirmed in the process of investigating the application of seismic design in the national industrial complex, information on seismic design data (design drawings, available materials and seismic design standards) managed inside the occupant enterprise is required to be submitted when moving in, which is used to establish a database of seismic status at the level of the Korea Industrial Complex Corporation. Second, the central government, local governments, and the industrial complex participate in the safety inspection of industrial complexes and conduct it jointly with safety agencies. However, since guidance inspection by the Korea Industrial Complex Corporation is not mandatory under the Industrial Aggregation Act, it does not have the authority to take the initiative if the tenant refuses or postpone it. Therefore, in order to take the initiative in carrying out joint safety inspections and checking follow-up measures on pointed out matters, a clause related to granting entry rights to tenant companies should be newly established. Third, unlike individual laws, such as the Chemicals Control Act, which obligates the submission of such information to safety management agencies, the information submitted to the Korea Industrial Complex Corporation is a report carried out with the consent of the tenant companies. Information of tenant companies managed by each individual law is also not disclosed to the Korea Industrial Complex Corporation without a request for information from related agencies, making it difficult to conduct practical guidance and inspection. Therefore, it is possible to reduce the incidence of accidents in industrial

complexes and to seek active countermeasures by creating a provision that allows sharing of safety information on electricity, gas and hazardous materials.

### **3) Establishment of support system for seismic retrofit of occupied company**

Small scale companies operating in the national industrial complex have difficulties in voluntarily carrying out seismic reinforcement due to difficulties in securing funds. It is necessary to secure the measures to prepare the support for national industrial complexes that are likely to spread to large-scale complex disasters. First, the Disaster Management Fund was operated under Article 68 of the Framework Act on the Management of Disasters and Safety to promote the seismic reinforcement project for existing public facilities, and as a result, the seismic rate of existing public facilities was improved to 62.3% (Ministry of Public Administration and Security, 2019). However, the scope of the seismic reinforcement project is limited to public facilities such as dams, roads, and ports, and it is difficult to apply the facilities of the tenant companies in the industrial complex with limited resources. In 2016, the Seismic-resistant Reinforcement Fund Act was proposed as a measure to secure funds needed for seismic reinforcement and emergency repair of educated facilities. In this regard, it is necessary to consider a plan to prepare and legislate a plan to create and operate a fund to support seismic reinforcement in industrial complexes.

Second, Japan plans to re-establish and revise the Act on the Promotion of Seismic Retrofit of Buildings to achieve a 95% seismic-resistant rate by 2020 while promoting the reconstruction of existing buildings or the improvement of earthquakes by 2025. The government prepared a system to support tax evasion and loans, such as support for domestic consumption, financial assistant for number and income tax cuts. In addition, administrative support such as introduction of special cases for ground area ratio and building to-land ratio, and certification marketing system for securing seismic performance of local government is provided (Huh, 2017; Kim, 2017; Sin, 2017). Referring to such a system, incentives are given to businesses operating in national industrial complexes at various levels, such as tax restrictions and loan support, to implement the certification system to promote voluntary participation of tenant companies in the seismic reinforcement. Third, the Ministry of Public Administration and Security was empowered to set up a dangerous zone, ban access, eviction, or order evacuation measures in the event of a disaster in accordance with the designated management guidelines such as facilities subject to specific management. It is necessary to consider a plan to introduce such a system to the Korea Industrial Complex Corporation to give the authority to suspend use and install no-access signs if the results of the seismic performance evaluation are very weak.

#### **4) Development of seismic inspection tools**

In order to fully investigate the seismic performance evaluation and inspection of buildings including work-pieces in the national industrial complex, it is necessary to develop support tools that can efficiently manage the as huge amounts of time and resources are spent. First, a manual containing standardized safety inspection standards and measures in the Korea Industrial Complex Corporation should be developed and distributed. Large companies that are relatively easy to secure safety management budgets and manpower can prepare their own inspection systems to systematically manage their own seismic-resistant reinforcement plans can be established and implemented. However, small tenants are left in a dangerous condition for some facilities due to difficulties in securing budgets and supplying safety experts. Therefore, by preparing and distributing standardized seismic inspection manuals and checklists, it can be used as basic data for establishing plans for seismic-resistant reinforcement and budgeting in the future by using them as the minimum inspection criteria for tenant companies. In addition, it can be used as educated materials for improving the professionalism of the safety managers of the tenant companies and the Korea Industrial Complex Corporation can also provide efficient safety inspections and guidance. Second, it is important to develop an industrial complex seismic hazard map. In order to minimize the amount of damage and efficiently manage it in the event of an earthquake disaster, information on areas and locations where vulnerable ground or facilities are concentrated in the national industrial complex is needed in advance. In Tokyo, Japan, as Figure no4, the risk level is relatively assessed at the local level every five years by dividing the risk into five scales, taking into account the risk of earthquakes and difficulties in activities such as evacuation or rescue in the event of a disaster. It is used as an indicator to select the priorities of seismic reinforcement plans and budgeting (Tokyo Metropolitan Government, 2015). The Korea Industrial Complex Corporation also conducts its own database construction and risk assessment for tenant companies in the complex to manage local risk information so that it can be used as data such as calculating damage-expected areas in the vent of an seismic disaster.



Figure no4: Tokyo Disaster Prevention Manual (<https://www.metro.tokyo.lg.jp/>).

Third, it is to develop and build a seismic design self-inspection system. As shown in Figure no5, the self-inspection system for seismic performance of buildings developed by the Seoul Metropolitan Government was able to verify the application of seismic design and the results of seismic performance evaluation by utilizing the facility information input and check-list. Considering the expertise of users using the inspection system and the accuracy of the input information, it is a simplified rough evaluation technique compared to the seismic performance evaluation conducted by specialized institutions. However, there is an advantage that it can be used as a role to induce the tenant company to recognize the risks and improve its performance.



Figure no5: Seismic performance self-inspection System in Seoul (<http://goodhousing.eseoul.go.kr/SeoulEqk/main.do>).

### 5) Strengthen education and promotion of seismic reinforcement

According to Article 45 of the Industrial Cluster Development and Factory Establishment Act, disaster management and safety guidance for the tenant companies of the industrial complex are as shown in Table 9. Each safety agency is taking the initiative in supporting education, public relations items, and the Korea Industrial Complex Corporation is playing a role in supporting them. In the event of an earthquake, it can spread to large-scale complex disasters where damage occurs to each facility, such as piping storage facilities and hazardous materials including gas and chemicals at the same time. In order for the Korea Industrial Complex Corporation to play the role of a general control tower as a disaster management agency in the future, it is necessary to establish an annual education and public relations road-map with a macroscopic perspective on the key managed items of each safety agency. To this end, the government can increase the efficiency of education and public relations by sharing and disseminating integrated information to related agencies by creating a clause that obligates the Korea Industrial Complex Corporation to notify educational and public relations data managed by each ministry through the revision of the relevant laws.

## IV. Conclusion

Earthquakes are frequent around the world, and in South Korea, the 2016 earthquake in Gyeongju has been confirmed to be the largest earthquake ever since the nation's earthquake observation. As the number of seismic detection continues to increase (Statistics Korea, 2018) due to the modernization of the seismic observation network and the improvement of the seismic analysis system, the importance of establishing efficient measures and management measures to prevent earthquakes, not seismic safety areas, is no longer

increasing. In particular, in the case of industrial complexes with high national economic contributions, manufacturing, storage and business facilities, as well as infrastructure, are concentrated, there is a high risk of causing massive economic losses along with human casualties in the event of an seismic disaster. Therefore, the this study aims to identify problems in the safety management of seismic disaster in national industrial complexes and to suggest measures for improvement.

To achieve the goal, the safety management system of the Korea Industrial Complex Corporation, the main body of the management of the industrial complex, and the interview with the working-level officials were conducted. A seismic design application survey was conducted at 28 national industrial complexes in parallel. The improvement plan was presented by considering prior research and expert opinions after integrating and rearranging the problems derived from the investigation process. Outlining the results derived from the above objectives and methods are as follows: First, the problems of seismic disaster safety management in the national industrial complex were identified as five categories: 1) insufficient legal regulations related to earthquakes, 2) lack of safety inspection guidance and authority, 3) insufficient support system for seismic reinforcement of occupants, 4) lack of seismic preparedness, and 5) opportunities for education and training of occupants and lack of teaching materials.

Second, the improvement measures for safety management of seismic disaster in national industrial complexes were classified into five categories and detailed plans for each items were presented: 1) Strengthen legal regulations related to earthquakes, 2) aligning the safety management system for industrial complexes, 3) establish a system to support seismic-resistant reinforcement of tenant companies, 4) develop tools to support seismic inspection, and 5) Strengthen education and publicity for seismic-resistant steel.

The improvement measures of the five items presented in this study can be used as a policy-making material for improving the seismic performance of national industrial complexes in the future. The scope of this study was limited to 28 national industrial complexes managed by the Korea Industrial Complex Corporation out of a total of 1,206 industrial complexes. As the application status of seismic design focused on literature research centered on the Building Management Registration and others is investigated, there is a limit to checking whether or not performance is achieved through the actual seismic performance evaluation. Therefore, it is necessary to establish a database for seismic design application that reflects the results of the seismic performance evaluation and on-site survey of buildings and to expand the scope to national industrial complexes.

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