Risk-Based Safety Impact Assessment Methodology for Underground Construction Projects in Korea

J. W. Seo, M.ASCE[1]; and Hyun Ho Choi[2]

Abstract: Safety of construction projects may be affected by various factors such as types and scale of projects, construction methods, safety management procedure, climate, site conditions, etc. Among them is the quality of design in relation to safety. Presently, however, designers typically are not involved in construction safety. They are often uncertain of their responsibilities in relation to construction safety and fail to be responsible for avoiding or reducing safety-related risks. In this study, the concept of safety impact assessment to achieve "design-for-safety" in the design phase is introduced. For this purpose, a safety impact assessment model was devised, and a methodology using the risk-based safety impact assessment approach for open-cut type underground construction projects in Korea is suggested. The suggested methodology includes a safety information survey, classification of safety impact factors caused by design and construction, and quantitative estimation of magnitude and frequency of safety impact factors. A checklist which can be easily used for assessing the safety performance of design products is also proposed. A real-world case study on the safety impact assessment of a subway construction project in Korea is also provided in the paper.

DOI: 10.1061/(ASCE)0733-9364(2008)134:1(72)

CE Database subject headings: Risk management; Safety; Construction management; Underground construction; Korea; Assessments.

Introduction

It has been recognized that safety accidents caused by many factors including collapse of structures, malfunction of construction equipment, lack of proper safety training, etc., are very likely to happen in the construction of large civil structures such as underground facilities. Therefore, the concerns for safety of construction projects are more increased to minimize the construction accidents and/or failures. Similar to the efforts of other countries, the Korean government has increasingly focused on the safety of construction projects so that intense regulations on safety management of construction processes have recently been enacted (MOCT 2002).

Among the many types of construction projects, underground construction projects are more subject to accidents due to uncertain and hazardous environments. Many lines of subway have been constructed and are being constructed in Korea forming the major portion of the underground construction. Unfortunately, there have been many accidents related to the underground construction for subway infrastructure development. The statistics combined by both the Seoul Metropolitan Subway Construction Headquarters (SMSCH 1997) and Korea Occupational Safety & Health Agency (KOSHA 2005) show that a total of 79 accidents have occurred during subway construction from 1990 to 2004. The major types of subway construction accidents are falling, collision, and explosion, constituting 24.05, 13.92, and 12.66% of the total number of accidents, respectively.

Safety of construction projects may be affected by various factors such as projects types, construction methods, safety management procedures, climate, site conditions, etc. Among them is the quality of design in relation to safety. Since many design decisions could affect safety of construction projects at the construction stage, careful attention to safety is required at the design stage. Presently in the design and/or planning stages, however, the project participants typically focus on the creation of safe end products that can carry the specified loading conditions, limiting themselves to no or minimal, if at all, involvement in construction safety. In other words, designers do not consider how safely the designed components could be built and how much impact the design components would bring to construction safety. This means that they normally do not take on the responsibilities in relation to construction safety and fail to exploit the potential of avoiding or reducing risks which are inherent in the construction processes and subsequent works. Therefore, it is determined that a central body of knowledge available for designers with regard to the impact of their design to safety is needed in order for them to be aware of how to build their design to improve and/or ensure safety.

The objective of this study is to develop a risk-based safety impact assessment methodology for underground construction projects in the design phase to consider "design-for-safety" (DFS). The suggested methodology includes a safety information survey, classification and importance evaluation of risk events, identification of the relationship between risks and design items, safety impact assessment with a checklist, and finally design sug-

[1]Assistant Professor, Dept. of Civil Engineering, Hanyang Univ., 17 Haengdang-dong, Seongdong-gu, Seoul 133-791, Korea (corresponding author). E-mail: jseo@hanyang.ac.kr

[2]Senior Researcher, Korea Highway Corporation, 430 Geomto-Dong, Sujeong-Gu, Seongnam, Kyungki, Korea. E-mail: padre@hanyang.ac.kr

Note. Discussion open until June 1, 2008. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on August 10, 2006; approved on May 3, 2007. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 134, No. 1, January 1, 2008. ©ASCE, ISSN 0733-9364/2008/1-72–81/$25.00.

Table 1. DFS Research Efforts of HSE and OSHA

Organization	Researcher	Contents	Year
Health and Safety Executive United Kingdom	Habilis Ltd.	Analytic methods of safe designing information through research for case studies related to design failure	2004
	Janet Davision	Capturing safety factors using knowledge based system & furnishing danger prediction and safe designing information	2003
	—	2002 serious accidents case-study research report in United Kingdom	2002
	Neil Storey	Introduction books of design for safety	1999
Occupational Safety & Health Administration United States	Elaine L. Chao etc.	Examining feasibility of OSHA regulations in underground construction site	2003
	Liz Bluff	Research on safe design and planning in construction industry	2003

gestions for safety improvement. The methodology can be summarized as the identification and evaluation of construction risk events that originate from the design and/or planning outputs, and the development of a checklist which is a practical tool to assess the safety performance of design. Moreover, the proposed methodology is applied to the construction safety assessment of a real-world open-cut type subway construction project that is being constructed in Korea.

Concepts and Research Trend of Safety Impact Assessment

DFS has been referred to as "the efforts to decrease construction accidents over the life-cycle in design and planning phases" (Storey 1999), which involves the definition of safety impact assessment in a broad sense. As a part of DFS, safety impact assessment in the design phase can be defined as "to assess the effect of design to safety in the design phase for construction projects in order to provide relevant information about design decisions concerning construction safety." In other words, safety impact assessment of construction projects plays a key role in achieving DFS by providing a way of evaluating the safety-related performance of design products to designers and planners.

Several previous studies on DFS of construction projects and preventing accidents/failures in the design phase were performed. Hinze and Wiegand (1992) introduced the concept of DFS by addressing the role of designers in construction worker safety. Gambatese and Hinze (1999) identified "best practices" for implementation during project planning and design in order to resolve safety hazards in the construction phase. A computerized tool to assist designers in identifying project-specific safety hazards and to provide best practices to eliminate the hazards was also devised (Gambatese et al. 1997; Gambatese and Hinze 1999).

DFS-related efforts made by government agencies are as follows: Health and Safety Executive (HSE) (United Kingdom) and Occupational Safety & Health Administration (OSHA) (United States) were involved in the implementation of the DFS process at the governmental level by making regulations and recommendations regarding DFS. HSE established construction design and management (CDM) regulations in 1994 where the roles and the duties of designers for construction safety are specified along with a guideline for DFS (HSE 1994). OSHA also actively included DFS plans in their strategic management plan, and performed research on DFS (Bluff 2003). The DFS-related research work of these governmental organizations is summarized in Table 1.

Safety Impact Assessment for Underground Construction Projects

Korea Infrastructure Safety & Technology Corporation (KISTEC) recently conducted research on safety impact assessment as an effort to reduce construction accidents by screening the design quality in relation to construction safety (KISTEC 2005). The type of construction selected initially for this research project was subway construction. The research basically aimed at developing a rigorous yet simple assessment procedure and related tools to review design products including plans and specifications of final and temporary facilities before construction. The procedure and tools devised for this research on risk-based safety impact assessment are described in this section.

Generally, risk-based safety impact assessment can be defined as a unified procedure that includes identifying, analyzing, evaluating, and managing the risks associated with construction projects. The risk-based safety impact assessment methodology proposed in this study is composed of the following five steps: (1) safety information survey for risk events and accident scenarios; (2) classification and importance evaluation of risk events; (3) identification of the relationship between the risks and design items; (4) development of a checklist; and (5) safety impact assessment with the checklist developed. These five major steps are explained in detail in the subsequent sections. While the methodology developed and/or approach could be applied to any kind of construction projects, the paper focuses on a type of underground construction project, an open-cut type subway construction that is widely adopted for urban development in Korea. Therefore, the procedures and tools of the proposed methodology described in the subsequent sections are based on the examples of open-cut type subway construction.

Safety Information Survey

This is the first step of the risk-based methodology for safety impact assessment. The safety information survey step is defined as follows: "to survey all possible risk-related information that could be used as a cause of risk events and to brainstorm all possible risk events and scenarios inherent in the construction projects." It is divided into two main parts. The first part is to survey information about the characteristics of the selected construction project such as type and scale of the project, construction methods, duration, workers, safety supervisors, constructors, subcontractor's safety-related performance, site conditions, etc. Then the accident data related to the selected type of projects need to be reviewed by investigating historical accident data or

J. Constr. Eng. Manage., 2008, 134(1): 72-81

Table 2. Example of Survey Sheet with Classification and Importance of Critical Risk Events

Work division	Subdivision	Safety impact factors	Immediate cause	Type of accident	Classification	Importance of risk: Magnitude	Importance of risk: Frequency
	Hand excavation	Excessive working in motion	Misstep	Casualty	Construction	Medium	Medium
		Unsuitable slope	Misstep	Casualty	Design	Medium	Medium
		Excessive working at rainy day	Misstep	Casualty	Construction	Medium	Medium
		Shallow excavation (2–4 m) without protection wall	Landslide	Casualty	Design	Medium	Medium
Trench excavation (for verification of subsurface utilities)	Machine excavation	Excessive machine trench excavation	Landslide	Casualty	Design	Medium	Medium
			Impact on existing Facility	Existing facility damage	Design	Medium	High
		Imperfection of safety device	Equipment overturn/ worker shock	Casualty/ equipment damage	Construction	Medium	Medium
		Untrained/ malfunction	Worker shock	Casualty	Construction	Medium	Low
		Worker access to operating radius	Worker shock	Casualty	Construction	Medium	Low
		Untrained machine handling	Equipment overturn/ worker shock	Casualty/ equipment damage	Construction	Medium	Low
	Traffic control	Signaler not arranged	Traffic accident/ claim	Casualty/ economic loss	Design	Medium	Low
		Unskillful traffic blockade/lead	Traffic accident/ claim	Casualty/ economic loss	Design	Medium	Low
		Negligence stuffs on road	Traffic accident/ claim	Casualty/ economic loss	Construction	Medium	Low
	Boring	Earthmoving nearby the machine	Worker shock/ equipment break down	Casualty/ equipment damage	Construction	Medium	Low
		Operation prior to removal of residual sand in drilling rod	Equipment break down	Equipment damage	Construction	Low	Medium
Pile driving	Pile welding	Electric leakage	Electrical shock	Casualty	Construction	Medium	Low
		Not wearing goggles	Loss of eyesight	Casualty	Construction	Medium	Low
		Excessive individual tasking	Loss of eyesight	Casualty	Construction	Medium	Low
		Welding machine malfunction	Scald	Casualty	Construction	Medium	Low
	Pile driver	Noise/quake	Impact to existing facility/ claim	Existing facility damage/ economic loss	Design	Low	High
		Worker access to falling hammer	Worker shock	Casualty	Construction	Medium	Low
		Signal discord	Worker shock	Casualty	Construction	Medium	Low
		Pile head not installed	Misstep	Casualty	Construction	Medium	Low

J. Constr. Eng. Manage., 2008, 134(1): 72-81

interviewing experts. Since these survey data provide background information for the identification of risk events, all possible risk-related information of the selected project has to be surveyed. After surveying the risk events of the selected project, the definition of a set of credible risk or accident scenarios that represent the occurrence paths of the critical risk events need to be developed as a second part. The process must involve an investigation into all the potential sources of risks and their consequences.

The risk events of the open-cut type subway construction were investigated for the research. The research team identified a total of 203 risk events based on accident data/history, safety manuals, interviews, and/or survey with safety experts. Thirty one contractors and engineers with more than 15 years of experience had participated in the interviews and the survey. An example of a survey sheet that includes the accident scenarios for "Trench excavation" and "Pile driving" work divisions, as part of a total of seven work divisions of the open-cut type subway construction project, is shown in Table 2. As shown in Table 2, the representative subdivisions of each work division are investigated. For developing the risk or accident scenarios, safety impact factors, intermediate causes, and types of accidents as a result are investigated. Here, safety impact factors describe specific events or environments that trigger accidents followed by the immediate cause. For example, the "Trench excavation" work division shown in Table 2 includes work activities involved in the excavation of pilot trench for verifying the existence of underground utilities. It is a very important work that should be preceded before the main excavation for open-cut type subway construction in the Seoul metropolitan area because information on the existing underground utilities is often incorrect or does not exist. In "Hand excavation" work activity of the "Trench excavation" work division may experience "Casualty" of the workers by landslide (collapse of trench wall). In this case the shallow excavation (2–4 m) specified in the design package without a temporary protection wall is the safety impact factor that causes the accident.

Classification and Importance Evaluation of Risk Events

This is a process of acknowledging critical risk events and identifying their characteristics for the selected type of projects based on the safety information survey. The classification of risk events screens the collected risk events and classifies the risk events according to the connection with the specific project stages. The purpose of this procedure, of course, is to choose the risk events and the safety impact factors that are related to the design stage. Table 2 also shows the classification of risk events according to the project stages along with the previously explained "safety information survey" items. "Construction" and "Design" shown in the "Classification" column means the risk events are originated from the construction and design stages, respectively.

The following part evaluates the importance of risk events. The importance of risk events is evaluated based on the measurement of the frequency of the risk events and the magnitude of the accident caused by the risk events as shown in the "Importance of risk" column of Table 2. A precise estimate of importance of critical risk events would be possible with detailed data on accident history including the cause and the resulting accidents, but lack of data often makes it very difficult. Therefore, what is reasonably practicable became the focus of this research. A crude range in-between the qualitative evaluation and the relatively sophisticated quantitative evaluation is used. As shown in the note of Table 3, three categories of the frequency and the magnitude are evaluated.

For example, the importance of "Excessive machine trench excavation (Existing facility damage)" and its consequence is evaluated as "High" by using Table 3, which is combined with "High" on frequency and "Medium" on magnitude as shown in Table 2. This type of risk matrix is useful for the purpose of risk assessment for categorizing the importance in terms of "frequency–magnitude" level.

Another survey was conducted with 31 survey participants for the identification of risk events at this stage. "Frequency(F)" and "Magnitude(M)" of the risk events of Table 2 were evaluated by the survey participants. In order to eliminate subjective judgment as much as possible, The Delphi approach (Dell'Isola 1997) was used. A questionnaire with the empty columns of "Classification" and "Importance of risk" was sent to the participants initially. After the result of the survey was compiled, another questionnaire along with the compiled result of the first survey was sent so that the participants could make a final decision after they referred to the outcome of the first survey.

Table 3. Importance Evaluation of Risk Events

		Magnitude		
Classification		Low	Medium	High
Frequency	Low	Low	Low	Medium
	Medium	Low	Medium	High
	High	Medium	High	High

Note. Frequency: "High"=certain or near certain to occur; "Medium"=reasonably likely to occur; "Low"=very seldom or never occur. Magnitude: "High"=many fatalities and injuries; severe damage or failure; "Medium"=fatalities and injuries; severe or certain damage; and "Low"=slight injuries; repairable damage.

Identification of Relationship between Risks and Design Items

Once the risks are surveyed and classified according to the project stages (Design or Construction) of the cause of risk events in the previous steps, all the potential design items are screened for further consideration concerning the relationship between the identified risks and the design items based on relevant design codes, accident case studies, safety manuals, and interview with design and/or construction experts. After screening the design items, the relationship between risks and design items is identified, and the closeness of the relationship is also examined. It is of considerable importance because the processes of safety impact evaluation and the response strategies may only be performed based on the potential risks identified and design items. Table 4 shows a checklist for identifying the relationship between risks and design items for the two work divisions of the open-cut type subway construction project. The "Design items" column of Table 4 shows the identified design items that trigger the risk events. For example, it is identified that "Shallow excavation (2–4 m) without protection wall" is closely related to the design item "Temporary land-slide protection wall" as shown in Table 4.

Safety Impact Assessment with Checklist

After identifying the relationship between the risks and the design items, the evaluation level of the design output of Table 4 needs to be filled. Only the risk events that have the relationship with design items along with the importance of risks are included in

J. Constr. Eng. Manage., 2008, 134(1): 72-81

Table 4. Developed Checklist of Subway Construction Projects

Work division	Subdivision	Safety impact factors	Type of accident	Design items	Importance of risk	Evaluation level	Risk level
Trench excavation (for verification of subsurface utilities)	Hand excavation	Unsuitable slope	Casualty	Suitable slope	Medium		
		Shallow excavation (2–4 m) without protection wall	Casualty	Temporary land-slide protection wall	Medium		
	Machine excavation	Excessive machine trench excavation	Casualty	Adequate excavation depth	Medium		
			Existing facility damage	Suitable method using GPR investigation	High		
	Traffic control	Signaler not arranged	Casualty/ economic loss	Appropriate signaler arrangement	Low		
		Unskillful traffic blockade/lead	Casualty/ economic loss	Traffic control plan	Low		
Pile driving	Pile driver	Noise/quake	Existing facility damage/ economic loss	Temporary soundproof plate in construction Low noise & vibration method	Medium		
Temporary work (Earth work)	Carrying equipment into a pit	Lack of contact pressure of crane outrigger	Casualty/ equipment damage	Bearing capacity	Medium		
	Excavation	Unsuitable excavation method	Flooding damage	Accurate reflection of yearly rainfall	Medium		
Temporary work (deck plate installation)	Main girder installation	Exceeding horizontal space of center-pile	Traffic accident	Horizontal space of center pile	Low		
		Overloading of live load	Casualty	Live load	High		
		Use of deterioration materials	Casualty	Service life of materials	Medium		
	Deck plate installation	Inferior slide-preventing equipment	Casualty/ equipment damage	Installation standard for slide-preventing equipment	Medium		
Temporary work (lagging/ bridging installation)	Lagging installation	Unsuitable lagging	Casualty/ equipment damage	Suitable quality of lagging	Medium		
		Misunderstanding of geological stats	Casualty/ equipment damage	Accurate geological coefficient	Medium		
		Underestimation of geological stats	Casualty/ equipment damage	Adequate thickness of lagging Adequate design earth pressure/ hydraulic characteristic	Medium		
		Underestimation of effect of underground water	Lagging breakdown	Loading conditions of underground water JSP,SGR design[a] Consideration of stratum characteristics Influent treatment plan	High		
	H-pile + Lagging	Over-impact to adjoined buildings	Casualty	Loads of adjoined buildings CIP method	Medium		

J. Constr. Eng. Manage., 2008, 134(1): 72-81

Table 4. (*Continued.*)

Work division	Subdivision	Safety impact factors	Type of accident	Design items	Importance of risk	Evaluation level	Risk level
	Earth-anchor installation	Unsuitable installation	Casualty/ equipment damage	Adding strut	Low		
	Pulling up/ installation strut	Fence not installed	Casualty	Plan for safety facilities	Low		
		Work for upper part of strut	Casualty	Attachment of safety bar	High		
	Safety path	Pathway for labor not occupied	Casualty	Safety path installation	Medium		
	Bridging bringing & installation	Connecting bridging	Casualty	Safety facility	High		
Earth work	Piling up soils & loading	Working path not occupied	Casualty	Plan for working path	Low		
		Signaler not arranged	Casualty	Plan for arrangement of signaler	Low		
	Excavation	Unsuitable excavation method	Casualty/ Equipment/ adjoined building damage	Suitable lagging/ reinforcement suitable excavation condition/stratum characteristic	Medium		
	Road excavating	Unsuitable traffic course work	Traffic accident	Traffic volume survey Traffic facility survey	High		
		Unsuitable traffic line	Traffic accident	Planning for traffic line of construction equipment	High		
		Unsuitable traffic management	Traffic accident	Traffic volume/ demand forecast survey Traffic control	High		
Blasting	Boring	Noise/Quake	Delay	Temporary soundproof wall Low noise/quake method	Medium		
	Blasting	Noise/Quake	Existing facility damage	Temporary soundproof wall Restricting amount of gunpowder/ blasting frequency	Medium		

[a]JSP=jumbo special place; and SGR=space grouting rocket.

the checklist. For example, the importance of "Excessive machine trench excavation (Existing facility damage)" is evaluated as "High," and the design item related to "Excessive machine trench excavation" is "Suitable method using ground penetrating radar (GPR) investigation." These relevant design items of a specific project in review should then be evaluated.

The evaluation level of design item is determined by the design quality in relation to the safety performance against the risk events. The risk level shown in the last column in Table 4 is then

Table 5. Evaluation Sheet for Risks and Design Items

Classification		Importance of risk (Magnitude and Frequency)		
		Low	Medium	High
Evaluation level (expert's opinion)	Excellent	Low	Low	Medium
	Good	Low	Medium	Medium
	Marginal	Medium	Medium	High
	Poor	Medium	High	High

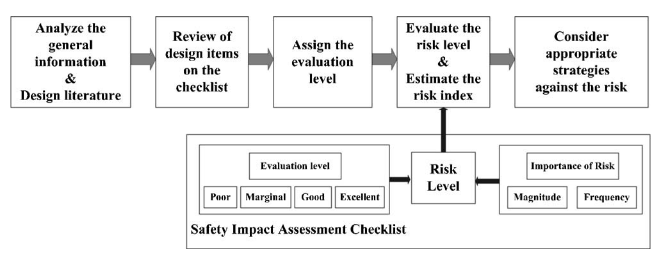

Fig. 1. Safety impact assessment procedures with checklist

J. Constr. Eng. Manage., 2008, 134(1): 72-81

Table 6. Example of Design Suggestions for Trench Excavation and Pile Driving

Work division	Subdivision	Safety impact factors	Type of accident	Design items	Object facility	Suggestions of design option
Trench excavation (for verification of subsurface utilities)	Hand excavation	Unsuitable slope	Casualty	Suitable slope	Ground of existing load Road near building	Designating suitable slope gradient, considering soil characteristics Reflecting as workers' safety education list Education for workers' overtask
		Shallow excavation (2–4 m) without protection wall	Casualty	Temporary land-slide protection wall	Earth retaining wall/plate Sheet pile	Planning false land-slide protection wall plan in a shallow excavation
	Machine excavation	Excessive machine trench excavation	Casualty	Adequate excavation depth	Ground of existing road Road near building	Designating adequate excavation depth according to specifications & site characteristics Indicating size, location and type of exiting facility in a plane figure Designating emergent barricading method preventing accidents extension
			Existing facility damage	Suitable method using GPR investigation	Ground of existing load Road near building	Appropriate design method for a particular site including many existing facilities Change of design (ex. suspension) in case of existing facilities
Trench excavation (for verification of subsurface utilities)	Traffic control	Signaler not arranged	Casualty/economic loss	Appropriate signaler arrangement	Location of arrangement of signaler	Flagman plot planning in traffic control of working space
		Unskillful traffic blockade/lead	Casualty/economic loss	Traffic control plan	Traffic control unit	Establishing traffic control process according to operation phase
Pile driving	Pile driver	Noise/quake	Existing facility damage/economic loss	Temporary soundproof plate in construction Low noise & vibration method	Temporary soundproof plate Low noise method (DRA[a] method, etc) Low vibration method	Appropriate construction methods of design fitting noise & vibration regulation Reflecting as supplementary design, collecting noise & vibration conditions and public petition Examination in moving existing facilities

[a]DRA=dual respective auger.

determined by the evaluation sheet for risks and design items shown in Table 5. Note that the evaluation level of design is grouped into four categories such as: "Excellent," "Good," "Marginal," and "Poor."

In summary, once a specific project of interest is selected, the safety impact assessment can be performed by the following procedure with the checklist developed. Fig. 1 describes the safety impact assessment procedure as well:

1. Analyze the general information of the selected project and design literature;

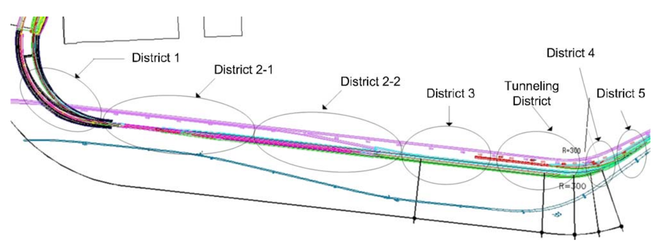

Fig. 2. Overview of subway construction project

J. Constr. Eng. Manage., 2008, 134(1): 72-81

Table 7. Characteristics of Each Alternative 1 and 2

Classification		Alternative 1	Alternative 2
District 1		H-pile + braced wall	Sheet pile
District 2	2-1	Sheet pile	Sheet pile + earth anchor
	2-2	Sheet pile	H-pile + braced wall + M.S.G.
District 3		H-pile + braced wall	H-pile + braced wall + M.S.G.
District 4		H-pile + braced wall + L.W.	C.I.P + L.W. grouting
District 5		H-pile + timber braced wall + S.C.W.	TRcM

Note: M.S.G.=micro silica grouting; C.I.P=cast in placed pile method; S.C.W.=soil cement wall; TRcM=tubular roof construction method; and L.W.=Labiles Wasserglass.

2. Review design items that are included in the checklist;
3. Assign the evaluation level of design items with respect to the associated risk event included in the checklist;
4. Determine the risk level with the evaluation sheet shown in Table 5 and estimate the overall risk index; and
5. Consider appropriate strategies against the risk.

Suggestion of Alternative Design Options

This step is the final step of the safety impact assessment procedure for avoiding or reducing the safety risks. This step suggests reconsidering the design items with the risk level evaluated as “High” or “Medium,” and providing designers with knowledge on safety risks inherent in design and information on how to improve the safety performance of the design. The alternative design options are suggested by investigating the design literature, surveying historical accident data, and interviewing experts. Table 6 lists examples of design suggestions for trench excavation and pile driving in subway construction project.

Case Study

In order to demonstrate the applicability and the effectiveness of the proposed methodology, the safety impact assessment was applied to a real world open-cut type subway construction project for the ninth subway line project in Seoul, Korea. The subway construction project selected is being constructed in the middle of Seoul. The length of the construction section is approximately 3,285.5 m. The expected period of construction is 6 years from 2002 to 2008. The construction area is divided into five districts excluding the tunnel section as shown in Fig. 2. For the safety impact evaluation, the checklist of open-cut subway construction projects that has already been developed as shown in Table 4 was used. The design items associated with the risk events based on the checklist were reviewed. Two design alternatives were considered for the project. Thus the safety impact assessment of the two alternatives was performed for comparison. Table 7 indicates the characteristics of alternatives 1 and 2.

Table 8. Checklist of Alternative 1

					District 2									
			District 1		2-1		2-2		District 3		District 4		District 5	
Safety impact factors	Type of accident	Importance of risk	Eval. level	Risk level	Eval. level	Risk level	Eval. level	Risk level	Eval. level	Risk level	Eval. level	Risk level	Eval. level	Risk level
Unsuitable slope	Casualty	Med.	Poor	High	Poor	High	Poor	High	Poor	High	Poor	High	Poor	High
Shallow excavation (2–4 m) without protection wall	Casualty	Med.	Exc.	Low	Mar.	Med.	Mar.	Med.	Exc.	Low	Exc.	Low	Exc.	Low
Excessive machine trench excavation	Casualty	Med.	Exc.	Low	Mar.	Med.	Mar.	Med.	Exc.	Low	Exc.	Low	Exc.	Low
	Existing facility damage	High	Exc.	Med.	Exc.	Med.	Exc.	Med.	Exc.	Med.	Exc.	Med.	Exc.	Med.
Signaler not arranged	Casualty/ economic loss	Low	Poor	Med.	Exc.	Low	Exc.	Low	Poor	Med.	Poor	Med.	Exc.	Low
Unskillful traffic blockade/ lead	Casualty/ economic loss	Low	Poor	Med.	Exc.	Low	Exc.	Low	Poor	Med.	Poor	Med.	Exc.	Low
Noise/quake	Existing facility damage/ economic loss	Med.	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low

Note: Eval. level=evaluation level; Mar.=marginal; Exc.=excellent; Med.=medium.

J. Constr. Eng. Manage., 2008, 134(1): 72-81

Table 9. Checklist of Alternative 2

Safety impact factors	Type of accident	Importance of risk	District 1		District 2				District 3		District 4		District 5	
					2-1		2-2							
			Eval. level	Risk level	Eval. level	Risk level	Eval. level	Risk level	Eval. level	Risk level	Eval. level	Risk level	Eval. level	Risk level
Unsuitable slope	Casualty	Med.	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low
Shallow excavation (2–4 m) without protection wall	Casualty	Med.	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low
Excessive machine trench excavation	Casualty	Med.	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low
	Existing facility damage	High	Exc.	Med.	Exc.	Med.	Exc.	Med.	Exc.	Med.	Mar.	High	Exc.	Med.
Signaler not arranged	Casualty/ economic loss	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low
Unskillful traffic blockade/ lead	Casualty/ economic loss	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low
Noise/quake	Existing facility damage/ economic loss	Med.	Exc.	Low	Exc.	Low	Exc.	Low	Exc.	Low	Mar.	Med.	Good	Med.

Note: Eval. level=evaluation level; Mar.=marginal; Exc.=excellent; Med.=medium.

With the importance evaluation of risk events previously performed for the checklist, the evaluation level of the design alternatives based on an expert's opinion are assigned to the checklist of Alternatives 1 and 2 for comparison. The risk level of the design alternatives with respect to the design items related risk events are then determined. For example, since slope check was not performed for Alternative 1, the evaluation level of the unsuitable slope was determined as "Poor." However, in Alternative 2, a safety check was performed by using a software program for slope stability analysis such as STABL 5M, SLPOE/W. Therefore, the evaluation level was determined as "Excellent." Similarly, the evaluation level of Noise/Quake was determined as "Excellent" except for Districts 4 and 5 in Alternative 2 because the low noise and vibration method was designed for construction, and a temporary soundproof plate was selected as a supplementary design.

Tables 8 and 9 show the completed checklist of Alternatives 1 and 2 with the evaluation level and the final risk level.

For this particular case study, the estimation of the risk index represented as the score was performed to make a comparison on the overall safety impact assessment of the alternatives based on the evaluation performed with the checklist to determine the risk level. Numerical values of 5, 4, and 3 were assigned as score to "High," "Medium," and "Low" of the risk level, respectively, to evaluate overall risk levels of the alternatives considered. Then, the total score was calculated by summing up all of the risk indices of the checklist. The results of the total score, i.e., risk index, based on the safety impact assessment of the subway construction projects for Alternative 1 and 2 are summarized in Table 10. It was observed that a distinct difference (19 points) exists between the results of risk index of alternative 1 (154 points) and Alternative 2 (135 points). Although the numerical values of the risk level were assigned subjectively, the overall risk level in terms of the total score could be reasonably interpreted by referencing the highest and lowest possible total scores (highest: 210, lowest: 126). Based on comparative observations, it was suggested that the design option of Alternative 2 could be constructed more safely if only the safety impact of the design items is considered.

The real value of the safety impact assessment can be realized by evaluating the design items that could cause construction accidents objectively, and then reducing the risks before construction rather than only comparing the evaluation results of different alternatives. In the case of Alternative 2, the risk level could be reduced based on the design suggestions made to improve the safety performance of the design options. The risk level of "Excessive machine trench excavation" of Alternative 2 was evaluated as "Medium" in all districts except District 4. The risk level of "Noise/Quake" was evaluated as "Medium" in Districts 4 and 5. This means that the risk needs to be reduced by requiring additional designs or changes in the current design such as: (1) an appropriate design method for a particular site with many existing

Table 10. Results of Safety Impact Assessment

Classification	Alternative 1		Alternative 2	
Risk level	High	6	High	1
	Medium	16	Medium	7
	Low	20	Low	34
Risk index	154		135	

J. Constr. Eng. Manage., 2008, 134(1): 72-81

facilities; and (2) change of design (e.g., suspension) in the case of old existing facilities. In addition, (1) a design satisfying more intense noise and vibration regulation; and (2) further examination on deformation of existing facilities, etc. could be adopted to improve the safety performance of design.

Conclusion

This paper presents a safety impact assessment methodology using a risk-based approach for underground construction projects. The proposed methodology includes a safety information survey, classification of safety impact factors occurring by design and construction, and quantitative estimation of magnitude and frequency. Moreover the checklist, which makes it possible to identify the relationships between risk events and design factors, is developed and the procedure of safety impact assessment with the checklist developed is also proposed. The proposed safety impact assessment was applied to a real-world open-cut type subway construction project for the ninth subway line in Seoul. Based on the results from the application of the safety impact assessment of the subway construction project, the main observations and findings of this study can be summarized as follows:

1. This study is the incipient research in Korea and anywhere else to secure safety of construction projects at the preconstruction stage and thus will have a scientific significance and contribute to the body of knowledge in civil engineering;
2. Since this study intends to develop a practical methodology, procedure, and tools for safety impact assessment, its consequent contribution to the engineering society would play a role in seeing that safety impact assessment is applied to various large infrastructures, and be helpful to related studies such as DFS;
3. With this proposed methodology being used in safety assessment for design, the technology of quantification of risks may become more readily acceptable to practicing engineers because of its simplicity and rigorousness; and
4. The development of a checklist for safety impact assessment and the case study presented in this paper focused on the open-cut type subway construction project in Korea. However, the proposed methodology could be applied to other types of construction projects with the framework suggested. In the future, the checklist of many types of construction projects could be enhanced, establishing D/B for safety impact assessment. Other types of underground construction that are being investigated by the research team for the development of a safety impact assessment checklist are tunneling and the underground work for building construction.

References

Bluff, L. (2003). "Regulating safe design and planning of construction works: A review of strategies for regulating OHS in the design and planning of buildings, structures and other construction projects." *Technical Rep. Working Paper No. 19*, National Research Centre for OHS Regulation, ANU.

Dell'Isola, A. (1997). *Value engineering: Practical applications*, RSMeans, Kingston, Mass.

Gambatese, J. A., and Hinze, J. W. (1999). "Addressing construction worker safety in the design phase designing for construction worker safety." *Autom. Constr.*, 8(6), 643–649.

Gambatese, J. A., Hinze, J. W., and Haas, C. T. (1997). "Tool to design for construction worker safety." *J. Archit. Eng.*, 3(1), 32–41.

Hinze, J. A., and Wiegand, F. (1992). "Role of designers in construction worker safety." *J. Constr. Eng. Manage.*, 118(4), 677–684.

Health and Safety Executive (HSE). (1994). "Construction (design and management) regulations 1994: The role of the designer." *Report No.*: *SI 3140 HMSO*.

Korea Infrastructure Safety & Technology Corporation (KISTEC). (2005). "The research of the regulations for safety impact assessment of construction projects." *Rep. No.*: *TS-05-R3-011*.

Korea Occupational Safety and Health Agency (KOSHA). (2005). "Analysis of fatal hazard causes." Seoul, Korea.

Ministry of Construction and Transportation (MOCT). (2002). "A statute of safety control and management in infrastructure construction." Statute of Ministry of Construction and Transportation, Seoul, Korea.

Storey, N. (1999). "Design for safety." *Towards System Safety: Proc., 7th Safety-Critical Systems Symp.*, Huntingon, U.K., 1–25.

Seoul Metropolitan Subway Construction Headquarters (SMSCH). (1997). *Subway construction safety management handbook I, II, III*, Handbook Series of Subway Construction Headquarters, Seoul, Korea.

J. Constr. Eng. Manage., 2008, 134(1): 72-81