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# SAFETY EVALUATION OF THE SELF-SUPPORTED STEEL JOINT FOR STEEL ERECTION WORK

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**ABSTRACT:** Recently, the scale of buildings has been increasing because of the high-rise trend and complexity of underground spaces. A significant number of steel structures have therefore been adopted for building construction. Since workers need to work in high places to install steel beams, many industrial accidents easily occur during steel-frame work. Furthermore, considering the increasing trend of building steel structures, the safety of the workers during the steel beam erection work is of concern. To improve the safety, a new type of joint, located between the steel column and beam, which can eliminate the need for working at the elevated height during steel beam erection has been developed in Korea. Using the newly developed technology in the construction field, the safety performance needs to be evaluated. This study presented the safety evaluation approach for the newly developed technology from the literature review, and applied the method to a self-supported steel joint. The result showed that applying the self-supported steel joint improved the safety of the steel erection work in terms of working posture, working environment, and risk exposure time.

*Keywords: Self-supported Steel Joint; Safety Evaluation; Steel Erection*

## 1. INTRODUCTION

Recently, the height of high-rise buildings has been dramatically increasing and underground spaces are becoming larger and more complex as they link with large buildings. Many steel structures are therefore being adopted for building construction because of their considerable ductility and constructability. Since workers need to ascend the columns or beams to install the steel-frame work, there is a significant concern about the occurrence of accidents. Especially, 37 percent of accidents that occur in the entire steel frame work installation have occurred during the steel beam erection work. Considering the increasing trend of using steel structures, the safety of workers during steel beam erection work needs to be improved.

In Korea, research for a new type of joint that can improve the process of steel beam erection work has been carried out and is now at the field testing stage. This new joint is called a self-supported steel joint because it does not need to be supported by a tentative assembly of bolts.

For the practical use of the newly developed technology, the performance needs to be verified. Kim et al. [1] verified the economics of the joint to show a reduction in the labor expense and Kim et al. [2] verified its constructability to evaluate the structural safety and work time reduction. Yang [3] evaluated the safety of a self-supported steel beam using a stochastic analytic hierarchy process, but the adopted criteria for evaluation is not sufficient to reflect the change of work process, although the application of the new joint results in a significant change in working posture, environment and time required for steel erection. Hence, this study presents the safety evaluation method from the literature review that is able to consider the change in the work process required by the self-supported steel joint, and apply the method to the self-supported steel joint to verify the safety improvement.

In the next section, we review the existing research on the safety evaluation for construction work and present the available method for a self-supported steel joint. Next, steel erection works for the conventional joint and self-supported steel joint are compared and analyzed by classifying them into unit work and detailed action. Finally, the safety of the self-supported steel joint will be measured by applying the presented method.

## 2. BACKGROUNDS

### 2.1 Safety Evaluation of the construction work

Safety is defined as a risk that does not exceed the maximum permissible limit and accordingly, in most research, a risk assessment has first been performed for the quantification of safety.

Risk assessment generally refers to the overall process of risk management which minimizes the potential risk by establishing an appropriate control measure after identifying potential risk factors in the workplace.

However, this study will limit the scope to making a decision about the applicability of the system by assessing the safety of the self-supported steel joint through risk assessment.

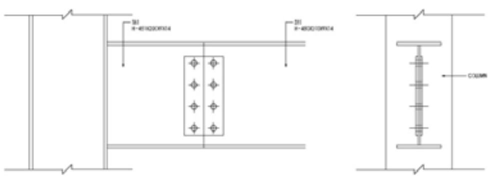
The term ‘risk’ means the strength and frequency of accidents which are caused by a hazardous condition. According to the definition of risk, safety evaluation is generally conducted by a method which combines potential risk occurrences and intensity of risk incidents. It is common to use statistics of recent disasters to determine the likelihood of risk events by using empirical evaluation methods assuming that the past experiences would be continued in the future. For the intensity of risk incidents, factors that were used included the length of sick leave and weight of the accident type or unit work.

However, because no practical accident cases are recorded since this study targets the newly developed technology, this study cannot be assessed in the same way as the existing studies. Hence, a suitable approach for the newly developed self-supported steel joint is required to measure the safety.

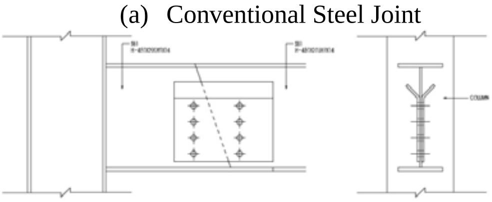
Table 1 shows the existing studies on the safety or risk assessment for construction work. Most studies used the risk assessment approach that is based on the statistics for industrial accidents on the site [4], [5], [6], [7]. Lee at al. [8] suggested a new approach for the safety evaluation of the automation system in a curtain-wall installation which has recently been developed. Therefore, this study intends to apply the measurement technique presented by Lee et al. [8] for the safety evaluation of a self-supported steel joint.

### 2.2 Self-supported Steel Joint

For safety improvement, the self-supported steel joint is designed to eliminate the need for working in elevated areas. Generally, when the steel beam is installed, the workers need to ascend the column to reach the bracket attached to the column and adjust the position of the beam. Subsequently, the workers assemble the beam tentatively with the bolts to support the beam. Furthermore, to unfasten the hooks of the tower crane, the workers need to walk on the beam that is supported by the tentative assembly to reach the center of the beam. This means that the need for working in an elevated position for steel beam erection is due to the beam positioning, tentative support bolting, and unfastening of tower crane hooks.



(a) Conventional Steel Joint



(b) Self-supported Steel Joint

**Table 1.** Literature Review for Safety Evaluation in Construction Industry

| Author | Contents |
|---|---|
| Lee, M. and Lee, C. [4] | Risk assessment considering the injury rate, accident frequency, sick leave from the statics of safety and health agency |
| Kim, D. and Kim, W. [5] | Suggestion of the safety evaluation method to combine the frequency and severity for each factors and apply to the steel beam erection work by accidents analysis in steel-structure work |
| Son, K. and Lee, S. [6] | Quantify the risk and determine the risk index though the survey to workers in the site about the frequency and the severity |
| Yang, Y. et al.[7] | Risk evaluation for each work in construction site through the portfolio of injury and fatality |
| Lee, S. et al.[8] | Analysis of safety improvement for automation system in curtain-wall installation the by considering the working posture, environment, and work exposure time. |

In the case of the self-supported steel joint, the slope of the bracket and the Y-plates that are pre-fabricated on the bracket as shown in figure 1 (b) means that the beam position can be found without the workers’ additional lead. Also, the bottom flange of the bracket has a cantilever structure, so the workers do not need to fasten the bolts for the support. To eliminate the need for an elevated position to unfasten the tower crane hooks, auto shackles are used for the self-supported steel joint.

Table 2 shows the unit works and detailed actions. The unit works are classified according to work processes such as preparation, beam lifting, installation and completion.

The preparation work involves inducing the rope installment and fastening the tower crane hook to the beam. While the tower crane lifts the beam, the workers climb the column and position themselves on the bracket that will be installed on the beam. Also, to position the beam, the workers grasp the inducing rope and adjust the position of the bracket. After positioning the bracket, the bolts are fastened tentatively to support the beam. For the completion work, the workers walk on the beam to unfasten the tower crane hooks, a task with significant risk. For the self-supported steel joint, the same preparation work is required. The beam is installed without the lead of worker, who sits on the elevated bracket, and the beam can be supported with the bottom flange of the bracket without bolting. Following the beam installment, the tower crane hooks are unfastened automatically by the auto shackles.

**Table 2**. Comparison of the Works of Conventional Steel Joint and Self-supported Steel Joint

| Unit Work | Worker's Detailed Action | |
|---|---|---|
| | Conventional Steel Joint | Self-supported Steel Joint |
| Preparation | Inducing rope installment | Inducing rope installment |
| | T/C hook fastening | T/C hook fastening |
| Beam Lifting | Climbing up the column to the bracket | - |
| Beam Installation | Beam positioning by worker on the bracket | beam positioning by self-load of beam |
| | Tentative bolting | - |
| Completion | T/C hook unfastening by worker | T/C hook unfastening by auto-shackle |

## 3. APPROACH FOR SAFETY EVALUATION

This study quantified the risk for safety evaluation, in which the working posture load, working environment, and risk exposure time are considered as the risk factors. Each risk factor is determined on a maximum 12 index (1~12), and the total risk is calculated by obtaining the geometric average for the risk index values of three factors according to the approach presented by Lee et al. [7]. The safety can be estimated by dividing the maximum index value (12) by the total risk index.

$$Risk = \sqrt[3]{PC \times WE \times WT} \quad (1)$$

$$Safety = \frac{12}{Risk} \quad (2)$$

In the equation (1), PC, WE, WT respectively means posture classification, working environment and working time. PC refers to the working posture load index, WE is the work environment Index, and WT is the risk exposure time index. Safety index is calculated with the total risk index like the equation (2).

### 3.1 Working Posture Load

In this study, the OWAS technique is considered for the working posture load. The OWAS technique has a detailed classification and has therefore been used for the construction work to analyze the workload. The OWAS categorizes the human anatomy according to back, arms, and legs, and the weight and strength of handling were also considered. From the OWAS, the improvement required in the work posture is evaluated into 4 action steps, and we define the risk index according to each action step as shown in table 3.

**Table 3.** OWAS Action Level and Risk Index

| Risk Index | Action Level | Corrective Actions |
|---|---|---|
| 1 | 1 | Work posture does not require any actions |
| 4 | 2 | Correction is needed in the work posture in the near future |
| 8 | 3 | Work posture must be corrected as soon as possible |
| 12 | 4 | Immediate correction is required in the work posture |

### 3.2 Working Environment

The risk factors of a working environment refer to the factors likely to cause various accidents, such as workers falling, overturning of the beam, crashing of steel members, and objects dropping or flying away, and so on. For quantification of the working environment risk, the correlation rate between each unit work and accident occurrence first needs to be surveyed. In this study, a correlation rate in 5 steps is suggested: 0, 25, 50, 75 and 100 percentage. The accident frequency also needs to be considered, according to the recent statistics of industrial accidents on construction sites as shown in table 4, and the frequency is calculated for each accident type.

**Table 4.** Statistics of Victim Number by Accidents in Construction Site (2009, South Korea) [9]

| Accident Types | Number of Fatality | Number of Others | Number of Conversion Victims | Frequency Rate (%) |
|---|---|---|---|---|
| Men Fall | 292 | 6,450 | 9,370 | 0.42 |
| Overturn | 27 | 3,592 | 3,862 | 0.18 |
| Crash | 17 | 1,926 | 2,096 | 0.10 |
| Object Fall & Fly | 40 | 2,658 | 3,058 | 0.14 |
| Collapse | 59 | 511 | 1,101 | 0.05 |
| Jammed | 17 | 1,978 | 2,148 | 0.10 |
| Electric Shock | 23 | 192 | 422 | 0.02 |
| Total | 475 | 17,307 | 22,057 | 1 |

The working environment risk can be estimated by multiplying the correlation rate and frequency rate. We assume that the case in which the correlation rate is 100 percent and the frequency rate is the highest in table 4, in which 42 percent of the men fall, is determined at the maximum index of 12, while other cases are determined by the index divided equally. This working environment risk index indicates 'to what extent the unit work relates to each accident', and 'the probability of each accident occurring during the unit work'.

### 3.3 Risk Exposure Time

The risk exposure time represents how long the workers need to stay in the dangerous environment, and is determined by the working time required for performing each unit work. The index evaluates the longest working time with a maximum index of 12.

**Table 5.** Index for Risk Exposure Time

| Index | range | Index | range | Index | range |
|---|---|---|---|---|---|
| 1 | 0-n | 5 | 4n-5n | 9 | 8n-9n |
| 2 | n-2n | 6 | 5n-6n | 10 | 9n-10n |
| 3 | 2n-3n | 7 | 6n-7n | 11 | 10n-11n |
| 4 | 3n-4n | 8 | 7n-8n | 12 | 11n-12n |

※ n = multiple of 12 more than the longest work time / 12

## 4. SAFETY EVALUATION OF THE SELF-SUPPORTED STEEL JOINT

According to the safety evaluation method presented, we evaluated the self-supported steel joint for the steel erection work. To achieve this, we recorded the related work in the pilot testing field and analyzed the postures of the workers. For the work environment risk factor, we surveyed the workers and researchers to determine the correlation rate for the work environment, and analyzed the frequency from the construction industrial statistics of 2009. We also recorded the time required to perform the entire steel erection work. The risk index for the self-supported steel joint according to the work posture, working environment, and risk exposure time is shown in tables 5, 6, and 7, and these can be compared in the conventional way.

**Table 5.** Work Posture Risk Index

| Unit Work | Conventional | | Self-supported Steel Joint | |
|---|---|---|---|---|
| | Action Level | Risk Index | Action Level | Risk Index |
| Preparedness | 2 | 4 | 2 | 4 |
| Beam Lifting | 2 | 4 | 1 | 1 |
| Beam Installation | 4 | 12 | 1 | 1 |
| Completion | 2 | 4 | 1 | 1 |

**Table 6.** Working Environment

| Unit Work | Conventional | | Self-supported | |
|---|---|---|---|---|
| | Percen tage | Risk Index | Percen tage | Risk Index |
| Preparedness | 1.8 | 1 | 1.8 | 1 |
| Beam Lifting | 15.8 | 5 | 2.1 | 1 |
| Beam Installation | 36.8 | 11 | 2.5 | 1 |
| Completion | 31.5 | 10 | 0.0 | 1 |

**Table 7.** Risk Exposure Time

| Unit Work | Conventional | | Self-supported | |
|---|---|---|---|---|
| | Time (s) | Risk Index | Time (s) | Risk Index |
| Preparedness | 59 | 4 | 59 | 4 |
| Beam Lifting | 60 | 5 | 60 | 5 |
| Beam Installation | 211 | 12 | 89 | 5 |
| Completion | 132 | 8 | 3 | 1 |

**Table 8.** Total Risk and Safety

| Unit Work | Risk Index | | Safety Index | |
|---|---|---|---|---|
| | Conven tional | Self-supported | Conven tional | Self-supported |
| Preparedness | 2.52 | 2.52 | 4.76 | 4.76 |
| Beam Lifting | 4.64 | 1.71 | 2.59 | 7.02 |
| Beam Installation | 11.66 | 1.71 | 1.03 | 7.02 |
| Completion | 6.84 | 1.00 | 1.75 | 12.00 |

Calculating the geometric average of the three risk indexes for each risk factor, the total risk and safety index can be evaluated as shown in table 8. With the exception of the preparation work, there is significant improvement in the beam lifting, installment and completion work. The safety index showed that the beam lifting was 3 times safer, the beam installment was about 7 times safer, and the completion work was about 7 times safer and these were compared with the erection work undertaken by the conventional joint. This means that the application of the self-supported steel joint for the steel beam erection can improve the work safety.

## 5. CONCLUSION

The self-supported steel joint is developed to improve the safety of the process of the steel beam erection work. For the practical use of this new technology, it is essential to evaluate and verify the performance. However, safety is relatively difficult to evaluate quantitatively, and when using general safety evaluation approaches, the statistics of practical accidents that have occurred in the past need to be analyzed.

Thus, we evaluated the safety of the self-supported steel joint through an approach that does not depend on practical accident cases and which can reflect the change of work process by applying the new joint. The safety of the steel erection work using the self-supported steel joint is measured to be 3 times safer for beam lifting, 7 times safer for beam installation and 7 times safer for completion work than the general method. This result is due to the elimination of the need to work in an elevated position and to reduce the time required for erection.

The self-supported steel joint has been being adopted for the automated construction system for the steel structure, and the research for practical use of automated construction system using the self-supported steel joint is being carried out in Korea. It is expected the self-supported steel joint can contribute to the automated construction in the steel structure work. Hence, for the verification of the application, it is required to extend the scope of assessment and evaluate the safety of the self-supported steel joint for not only the beam erection work, but also the entire steel structure work.

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