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Development of an Adjustable board and a Rotational Board for Scaffold

Myunghoun Jang
Department of Architectural Engineering, Jeju National University, Jeju, 63243, Republic of Korea
Email: jangmh@jejunu.ac.kr

Abstract. Scaffold is widely used in high work-places inside and outside of a building construction site. It is inexpensive and is installed and dismantled easily. Although standards and ledgers of a steel tube and coupler scaffold are installed in a regular distance, the distances of transoms are not equal in some places. Sometimes a working platform or a board is absent in the corner of scaffold. This may cause safety accidents because a foothold is not stable on the transoms. An adjustable safety board and a rotational safety board are suggested in this paper. The adjustable board consists of two footholds. The small one is inserted into the large one. The rotational board covers not only right angle but also acute or obtuse angles. These safety boards for scaffold help to decrease safety accidents in construction sites.

1. Introduction
Curtain walls or stone panels are used for the exterior of a building. And, finishes with paint or tiles are often used in flat houses or a small house. These finish works require scaffold because the most works are performed in high-place.
A tube and coupler scaffold [1], [2] has steel tubes and clamps. Vertical tubes (standards) are connected to horizontal tubes (ledgers) via right angle clamps. Diagonal tubes (transoms) are periodically connected to the scaffold via swivel clamps in order to stabilize the scaffold. It is common in construction.
Planking or walking boards are placed between transoms installed periodically. In some case, the distance between transoms is not equal, so the walking board is not fixed strongly with the transoms. Fig. 1(a) shows a board installed unsafely that is longer than the distance between the transoms. This board may fall and cause a safety accident. Sometimes scaffold boards are not connected in a corner as shown in Fig. 1(b). The disconnected scaffold is very dangerous to work.

(a) A board longer than the distance between transoms  (b) Boards disconnected in a corner

Figure 1. Scaffold boards installed unsafely
2. Safety Accidents
According to KOSHA [3], the number of workers and fatal injuries of all industries in 2015 are shown Table 1. The fatal injuries in construction industry are 437 persons (45.8%) and they are very larger than those of manufacture industry (251 persons, 26.3%). FRTTY (number of fatality rate per 10,000 workers by year) of construction industry is 1.30, and it is larger than all industry (0.53) and manufacture (0.60).

Table 2 shows the accident types of non-fatal injuries and fatalities in all industries. Various types of safety accident happened. Among them, the number of slip and tip (15,632 persons) is the highest, the second is fall and drop (14,126 persons), and the third is getting caught-in (13,467 persons). The fatalities are 339 persons in fall and drop, 121 persons in getting caught-in, and 96 persons in collision except traffic accidents. Fall and drop accidents accounted for over 35% of all fatalities.

<table>
<thead>
<tr>
<th>Industry</th>
<th>No. of workers (persons)</th>
<th>No. of fatalities Persons</th>
<th>Ratio (%)</th>
<th>FRTTY*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>17,968,931</td>
<td>955</td>
<td>100.0</td>
<td>0.53</td>
</tr>
<tr>
<td>Construction</td>
<td>3,358,813</td>
<td>437</td>
<td>45.8</td>
<td>1.30</td>
</tr>
<tr>
<td>Mining</td>
<td>11,615</td>
<td>4</td>
<td>0.4</td>
<td>3.44</td>
</tr>
<tr>
<td>Manufacture</td>
<td>4,161,536</td>
<td>251</td>
<td>26.3</td>
<td>0.60</td>
</tr>
<tr>
<td>Electricity, Gas &amp; Water supply</td>
<td>64,244</td>
<td>3</td>
<td>0.3</td>
<td>0.47</td>
</tr>
<tr>
<td>Transportation, storage, &amp;</td>
<td>805,403</td>
<td>88</td>
<td>9.2</td>
<td>1.09</td>
</tr>
<tr>
<td>communication</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forestry</td>
<td>86,565</td>
<td>15</td>
<td>1.6</td>
<td>1.73</td>
</tr>
<tr>
<td>Agriculture, Financing &amp; Insurance</td>
<td>8,701,072</td>
<td>149</td>
<td>15.6</td>
<td>0.17</td>
</tr>
<tr>
<td>Etc</td>
<td>779,68.</td>
<td>8</td>
<td>0.8</td>
<td>0.10</td>
</tr>
</tbody>
</table>

* FRTTY: Fatality rate per 10,000 workers by year

<table>
<thead>
<tr>
<th>Type</th>
<th>Injuries (persons)</th>
<th>Ratio (%)</th>
<th>Fatalities (persons)</th>
<th>Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>82,210</td>
<td>100.0</td>
<td>955</td>
<td>100.0</td>
</tr>
<tr>
<td>Fall &amp; Drop</td>
<td>14,126</td>
<td>17.2</td>
<td>339</td>
<td>35.5</td>
</tr>
<tr>
<td>Slip &amp; Trip</td>
<td>15,632</td>
<td>19.0</td>
<td>16</td>
<td>1.7</td>
</tr>
<tr>
<td>Crush &amp; Overtun</td>
<td>2,321</td>
<td>2.8</td>
<td>69</td>
<td>7.2</td>
</tr>
<tr>
<td>Collision</td>
<td>6,658</td>
<td>8.1</td>
<td>96</td>
<td>10.1</td>
</tr>
<tr>
<td>Flying object</td>
<td>7,151</td>
<td>8.7</td>
<td>59</td>
<td>6.2</td>
</tr>
<tr>
<td>Collapse</td>
<td>476</td>
<td>0.6</td>
<td>34</td>
<td>3.6</td>
</tr>
<tr>
<td>Getting caught-in</td>
<td>13,467</td>
<td>16.4</td>
<td>121</td>
<td>12.7</td>
</tr>
<tr>
<td>Cut, Puncture</td>
<td>8,743</td>
<td>10.6</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>Explosion</td>
<td>589</td>
<td>0.7</td>
<td>50</td>
<td>5.2</td>
</tr>
<tr>
<td>Traffic accident</td>
<td>4,342</td>
<td>5.3</td>
<td>97</td>
<td>10.2</td>
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<td>Improper action</td>
<td>3,090</td>
<td>3.8</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Etc</td>
<td>5,615</td>
<td>6.8</td>
<td>70</td>
<td>7.3</td>
</tr>
</tbody>
</table>
2.1. Cases of Scaffold Foothold
The sliding type safety foothold [4] has two boards as shown in Fig. 2. The one is larger than the other. The small board is inserted into the big board to adjust its length. The big board has guide rails and supporting bars across the rails. The big and small boards have so little difference of height that a worker does not slip or trip. But, the safety hooks in the end of the board are too weak to connect the board and a transom.

Fig. 3 shows the portable working way for construction site [5] which has a main platform and a sub platform. The two platforms are fixed to each other with pins. The main platform’s tip is slightly thin for a worker to walk without any obstacle. A fixing material which fixates the board with scaffold bearers is separable and is connected with a connecting material. The safety board with a sliding foothold [6] has fixed length as shown in Fig. 4. The sliding plate is not only a working platform but also a door to move downward when it is open. A safety accident may happen when the sliding foothold is close incompletely.

Fig. 5 shows a foothold [7] developed for a curved wall and corners. The foothold has a main board with two holes and a rotational head with two plugs. The main board and the head are linked using nut and bolt. One foothold is connected other foothold putting the plugs into the holes. The pin connection enables the head to rotate, so several footholds are installed to scaffold along a curved wall. But, the gap between the main board and the triangular head may make a worker’s foot be trapped or may cause material drop.

![Figure 2. A sliding type safety foothold](image)
2.2. Development of an Adjustable Safety Board

It is important to find a method to lengthen and shorten the length of the board and to fix the board with the scaffold in order to develop a scaffold board with adjustable length. The previous cases use two boards or platforms different in size. This research also uses the idea of sliding style, but add an idea to fix the board with scaffold’s transoms.

An adjustable board for scaffold [8] consists of two footholds as shown in Fig. 6. The small foothold is inserted into the large foothold to adjust the length of the board, and the small one is pull and pushed in order to adapt the distance between transoms. The length of the board is limited by a stopper which prevents the small frame and the large one from being separated apart.
There are linear grooves on the surface of the board not to be slippery. The middle cover is fixed into the grooves, and has a small slope that prevents stumbling owing to the height difference between the small frame and the large frame.

A circle-like hook is added at each end of the safety board as shown in Fig. 7. It holds a transom to install the board to the scaffold and closes by a pin. The board is safe from wind, live and dead load, or other impact because the board cannot be separated without removing the pin.

Fig. 8 shows a full-scale model of adjustable safety board installed to scaffold. The scaffold consists of standards, ledgers, and transoms which are fixed by clamps with each other. The full-scale model shows that it is easy to install and dismantle the adjustable safety board.

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**Figure 6.** The adjustable safety board

**Figure 7.** Section of the adjustable safety board
2.3. **Development of a Rotational Safety Board**

A rotational safety board \[9\] is composed of a main platform and a rotational platform as shown in Fig. 9. The main board has two hooks to install to a transom, but the rotational board has fixing frames to place over a custom board without any hook. The custom board is a linear and fixed length working platform with hooks.

The rotational board rotates freely on the rotational axis, thus it is used not only at a right angle but also at an acute or obtuse angle. Fig. 10 shows installation examples. The hooks of the main platform grasp a transom and the fixing frames lock the rotational platform over a custom board installed to other transoms. The rotational platform has sloped edges in order not to trip on the rotational platform.
2.4. **Structural Safety Analysis**

A rotational -- The adjustable safety board and the rotational safety board are composed of two parts connected with each other. The connected parts are so weak for bending or deflection. Thus, structural analysis is performed to review the safety of the boards.

Sections of the safety board are designed shown in Fig. 11 according to Korean Standards [10]. The Standards regulate that the bending performance should resist the bending power on the center of the board and the deflection of the center should be less than 10 mm. The overlapped part of the components of boards is also included in the analysis.

![Diagram showing dimensions of the sub frame and main frame](image)

(a) Dimensions of the sub frame  
(b) Dimensions of the main frame

**Figure 11.** Design of the adjustable safety board

![Diagram showing rotation on the board center and the instant deflection](image)

(a) Rotation on the board center  
(b) The instant deflection

**Figure 12.** Design of the adjustable safety board

Comparing the stress on the section over the maximum bending moment (2.04 kNm) with the allowable stress assuming the weight (4,400 N) is loaded on the center of the board (1,850 mm), the maximum stress of the main and sub platforms are 58.8 MPa and 64.8 MPa respectively. Because each maximum stress is less than the allowable stress (156 MPa) of SS400, the bending performance is structurally safe.

Rotation (2\(\phi\)) and instant deflection (\(\delta_i\)) occur on the board center shown in Fig. 12, and are calculated by the gap (h) between the main and sub frame and the overlapped length (l\(a\)) in the equation (1) and (2).

\[
2\phi = \tan^{-1}\left(\frac{h}{l_a}\right) \quad (1)
\]

\[
\delta_i = \tan \phi \times \left(\frac{l}{2}\right) \quad (2)
\]

The flexible deflection is 3.0 mm calculated by MIDAG GEN when the weight of 4,400 N is loaded on the center of the board (1,850 mm long). The total deflections are the sum of the instant deflection and the flexible deflection. Fig. 13 shows that the overlapped length should be more than 650 mm so that the total deflection of the board center is less than the allowable deflection in Korean Standards.
The research develops the adjustable safety board for irregular period between transoms of scaffold and the rotational board for a corner of scaffold. The small frame of the adjustable board is inserted into the large frame to adjust the board length. The shortened or lengthened board can be installed on the transoms shorter or longer than regular distance. A full-scale model is made to review the proposed safety boards to investigate the function of adjustable length and the hooking materials.

The rotational board can be used at any angle of a corner because the rotational platform rotates freely. It is installed over a custom board and is fixed strongly with fixing frames. Structural safety is analyzed according to Korean Standards. The result shows the stress and deflection on the center of the board is allowable. But, mock-up test is necessary for full-scale models to ensure safety.

The proposed safety boards can reduce safety accidents in scaffold. But, the verification for reusability and production cost decreasing is necessary to use them on a building construction. The combination of adjustable and rotational functions is developed in further studies.

4. Acknowledgments
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5. References