Simple countermeasure for preventing falls from portable ladders and residential roofs

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This study focuses on an effective countermeasure for preventing fall accidents that occur in Japan’s construction industry, especially during short-duration projects, such as residential repair work. Falls from residential roofs and ladders are particularly frequent. To resolve this problem, this research proposes a new straightforward fall prevention method that involve the use of a portable ladder, two nylon ropes, and a retracting device. To confirm the level of safety provided by the proposed method, experiments on a full-scale residential roof were carried out with the use of a human dummy called Hybrid-III, which is employed in the safety tests in the automobile industry. The findings show that the method sufficiently ensures safety against falls from both ladders and residential roofs.

Keywords: falling accidents, roofing works, ladder safety, short duration work, fall arrest system

1. Introduction

A long term analysis of the labor industry in Japan indicates that the number of labor accidents in the country has decreased, but recent developments appear to point to a reversal, with accident occurrence increasing in recent years1). The accident types with the largest occurrence rate are falls, particularly those from residential roofs and ladders. In Japan, projects related to residential roofing are major undertakings.

The basic countermeasures for fall prevention are the establishment of work floors and the installation of guide rails for construction work performed at heights. A problem is that the benefits presented by these preventive measures are difficult to realize in disaster sites, where construction work is primarily of a short-term nature.

Considering this issue, this study puts forward a new fall prevention method that can be easily adopted in sites where residential roofing work is conducted. The paper discusses the features of the proposed method and the verification experiments carried out on the approach.

2. Overview of the proposed countermeasure

Figure 1 shows an overview of the proposed countermeasure. The features of the method are as follows:

(1) The purpose that underlies the countermeasure is to enable workers to descent safety to the ground even as a fall accidents take place.
(2) This safe descent is ensured by the use of a portable ladder, four nylon ropes, and a retracting device equipped with a shock absorber.
(3) Alternatively, falls from roofs are prevented with the use of lifelines, and hook attachments.
(4) The portable ladder used in this system conform to the JIS2) standard, and the bucking load is about 4 kN. The maximum design load of the retracting device is about 3 kN.
(5) For the method to be effective, workers are required to wear a full harness at all times3).

2.1 Assembly methods for the fall prevention equipment

Figures 2 to 5 depict the methods of assembling the foundational equipment for fall prevention. The first step in the assembly is to connect two upper side support ropes and the retracting device with the shock absorber to a ladder, which is fixed on the ground as shown in Figure 2. The support ropes and retracting device should be attached to each of the ladder’s columns to avoid exerting impact force on the rungs. A special connecting rope for the retracting device is used.
The second step is to position the ladder in an upright position against the eaves at the correct angle as shown in Figure 3. When angular instructions are disregarded, a relatively large bending moment acts on the ladder, and slippage at the bottom of the ladder columns may occur because of increased horizontal force.

The third step is to attach the two upper side support ropes to a rigid structure, such as a column as shown in Figure 4. The support ropes are intended to provide high or low tension. The distance between the point of attachment on the rigid structure and the center of the ladder is about 1.8 m. Equipment such as belt slings and carabiners are unnecessary, but may still be useful for the assembly.

The fourth step is to fasten two under side support ropes to the bottom of the ladder columns as shown in Figure 5. In the procedure, the support ropes are also designed to provide high or low tension. A worker should use the retracting device with the shock absorber and maintain the three point support as he climbs up and down the ladder.

When additional countermeasures are required for work, the procedures illustrated in Figures 7 to 10 should be carried out.
2.2 Assembly methods for the alternative countermeasure

Figures 7 to 10 show the assembly methods for the alternative preventive measure, which features the use of lifelines and retracting devices. After a worker climbs up to roof eaves, he should hang a hook attachment to the eaves as shown in Figure 7. One of the important requirements in this sequence is to keep worker position within 0.5 m from the center of the ladder columns. Exceeding this distance may prevent the foundation from resisting the impact force due to falls. A consequent possibility is that the foundation may collapse. Another important step is to position the strap of the retracting device on the outer side of a ladder column. When a strap is faulty, the impact force due to falls will act on the ridge and may destroy the ladder.
The seventh step is promptly to climb and get over the ridge with holding the main rope as shown in Figure 8. The worker should also maintain a position within 0.5 m from the center of the ladder columns.

The eighth step is to connect a new retracting device to the main rope and replace the strap previously attached to the ladder with a new one as shown in Figure 9. A critical requirement is to maintain the connection between either of the straps and the full harness.

The final step in the assembly is to hang a hook attachment to the opposite side of the eaves as shown in Figure 10. In this stage, a worker is kept from falling by the new retracting device set near the ridge. The main rope should be fixed with high or low tension.

If roof work is conducted near the bilateral verges of a roof, a support rope for lifelines as shown in Figure 1 must be installed. This countermeasure involves the use of a main rope and a retracting device.

3. Verification experiments

During assembly work, safety should be ensured under the following condition.

1. A worker losses balance while climbing up a ladder.
2. A worker transfers to roof eaves from a ladder.
3. A worker losses balance just getting over a ridge.

Verification experiments were carried out for these cases.
3.1 Experimental methods

Figure 11 illustrates the outline of the experimental system, in which a full-scale residential roof and a human dummy, called HybridIII pedestrian 50%tile model employed in the safety tests in the automobile industry were used. The weight of the dummy is 735 N. The roof surface is made of plywood. The height of the eaves is 4 m and the angle is 21.8 degree (the angle generally applied in the Japanese residential houses). The impact force acting on four support ropes and a retracting device were measured by load cells at each joint. The sampling frequency was set at 1000Hz. The posture of the dummy during falls was captured by two high-speed cameras at 500Hz. Figure 11 identifies directions such as left and right sides in this experiments.

![Figure 11 Outline of the experimental system](image)

3.2 Experimental results

Three experiments were carried out under the same conditions. Figures 12 to 15 show the movement of the human dummy during falls in each of the cases. In every case, the human dummy was prevented from crashing to the ground.

Figure 12 shows the case wherein a worker loses balance on a ladder. The human dummy was dropped from a height of 1 m by using a separating device. The leg of the dummy firstly dropped on the ring. After that the dummy fall down again. However, the dummy did not crash to the ground because it was protected by the retracting device. Figure 15 indicates the time history of the impact force acting on the four support ropes and retracting device. The maximum force acting on each support rope was at a low value of 0.5 kN, whereas the maximum force acting on the retracting device was about 2.5 kN. The shock absorber was unnecessary for this case given that the maximum design load of the shock absorber is about 3 kN. Hence, the maximum impact force was assumed to about 2.5kN under the same conditions.
Figure 12 Movement of the human dummy during falls
(Loss of balance on the ladder)

Figure 13 Movement of the human dummy during falls
(Loss of balance when a worker transport to the eaves from the ladder)

Figure 14 Movement of the human dummy during falls
(Loss of balance when a worker just climbing over the ridge)
This tendency is similar to that observed in another experiments characterized by the same conditions. Table 1 shows the maximum force values derived in all the experiments.

Figure 13 depicts the case wherein a worker loses balance as he transfers from a ladder to eaves. The human dummy fell from the right side of the ladder column, and the ladder bent toward the right direction because of the impact force. Nevertheless the foundation remained stable. Figure 16 illustrates the time histories in this experiment. A very small impact force acted on the four support ropes. Most of the impact forces acted on the ladder via the retracting device. The maximum impact force was about 3 kN, and the shock absorber was used in all the cases under the same conditions. The findings indicate that a shock absorber should be used to minimize the risk of ladder collapse.

Figure 14 shows the case wherein a worker loses balance as he gets over a ridge. The human dummy fell from the right side of the ladder column, and the ladder significantly bent towards the right direction. Despite these phenomena, the descent of the human dummy was stalled, without the dummy crashing to the ground. The ladder also remained stable. Figure 17 displays the time histories in this experiment. The impact force acted not only on the retracting device but also on the two left-side support ropes. After the ladder bent toward the right side, the left-side ropes were used to stop the rotation of the ladder. The maximum impact force acting on the support rope was about 1 kN. The shock absorber was not worked in all the conditions in this experiment. The maximum impact force is therefore assumed to be less than 3 kN under the same conditions.

<table>
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<th>Experiment</th>
<th>rope (left, underside)</th>
<th>rope (right, underside)</th>
<th>rope (left, underside)</th>
<th>rope (right, underside)</th>
<th>retracting device</th>
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<td></td>
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<td></td>
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<td>0.03</td>
<td>0.07</td>
<td>2.12</td>
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<tr>
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<td>0.10</td>
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</table>

Unit: kN

Figure 15 Time histories of the impact force due to falls (loss of balance on a ladder, sample-1)

Figure 16 Time histories of the impact force due to falls (loss of balance when a worker transfers the eaves from a ladder, sample-1)
4. Summary

This study puts forward a new fall prevention method that can be easily applied in work sites where residential roofing work is conducted. The method was subjected to verification experiments to determine the level of safety provided by the approach. The experiments were conducted with consideration for three cases: (1) a worker loses balance on a ladder; (2) a worker loses balance as he transfers from a ladder to eaves; and (3) a worker loses balance as he gets over a ridge. A retracting device with a shock absorber should be used because the maximum force acting on the ladder can possibly exceed 3 kN, indicating that a ladder may collapse because of impact force. The maximum force acting on the support ropes was about 1 kN. This value and a safety index should be considered in the designing the force and stiffness of support ropes.

References

