The Method of Setting Slope Stakes in Road Construction Using 3-D Design Model

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Key words: Alignment, Total station, slope stakes, 3-D design model.

1. INTRODUCTION

The slope stake installation is time-consuming work and has to be done by experienced surveyor and a workman who helps him. Despite of the drastic advancements in measuring equipment, this installation has not become easier for everyone anywhere.
Although Japan has been introducing IT into the construction market and attempting to simplify and speed up the process, the slope stake installation has not been changed over the past 40 years.

Why can't it be done easier and in a short time?
And so we looked over the process of the slope stake installation and analyzed why it required experience. We set up the following 3 targets and developed a system to improve the process.

- Simple method for everyone
- A short time installation
- Higher accuracy

We also conducted verification experiments and confirmed the effectiveness of the system.

2. THE SLOPE STAKE INSTALLATION SYSTEM

2.1 The present situation

Here is the picture of the slope stake installation.

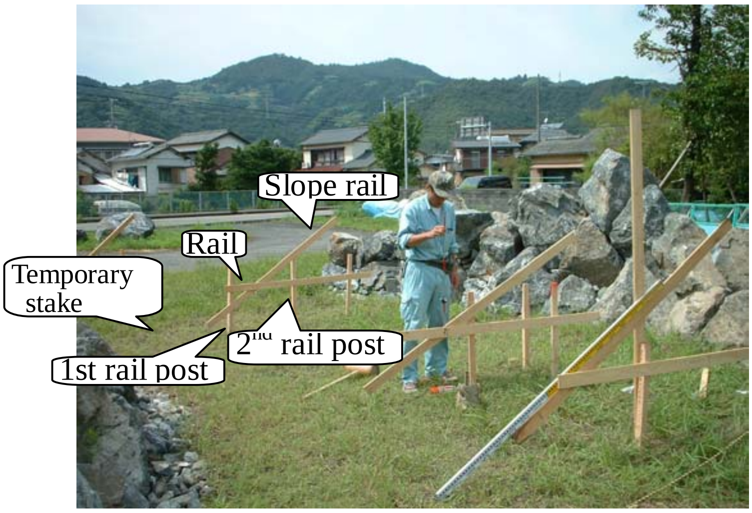


Fig. 1: The slope stake installation

The slope stake installation is comprised of 4 items, the 1st rail post, 2nd rail post, a rail and a slope rail as shown in the figure 1.

A slope rail actualizes the exact scale of the design slope gradient. It is the landmark for the staring point of an excavation and used to check the butter slope. A rail is used to place the U-Ditch.
The below is the present process of the slope stake installation.

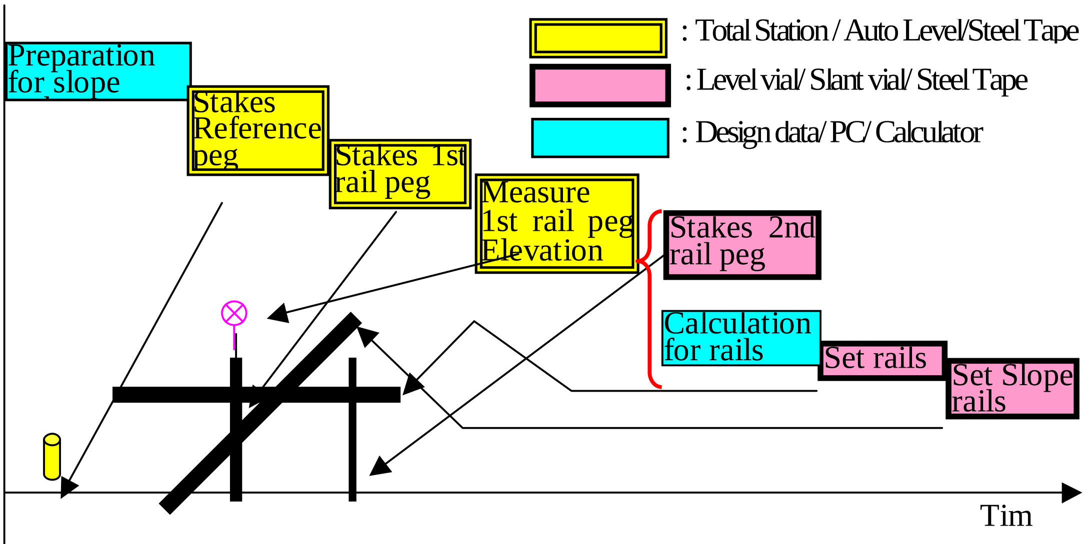


Fig. 2: Diagram of the present process

Figure 2 shows the present process in chronological order.

2.1.1 Pre-calculation

Pre-calculation is necessary to calculate the coordinates (x, y) of the temporary stake and the 1st rail post of the figure 1.
The design data essential for the pre-calculation are horizontal alignment data and cross section data.
The present method is also computerized, and once you put the design data, the coordinates are automatically calculated. However, it requires time to check the calculated value and takes time if alignments get longer.

2.1.2 Slope stake installation

There are 6 processes to set the slope stake.
The first 3 steps need Total Station. The rest is done by tools. This installation depends on natural surface but generally takes 15 to 18 minutes. The ratio of Total Station used is 1/3 to 1/5 of the total processes.

2.2 Problems

The problems were found from the present situation of 2.1

2.2.1 Experience is required

The 1st rail post (Fig. 1) is set up at the point that is offset a little from the intersection of the natural surface and the design slope gradient of the cross section data. (See figure 3.) This

offset is determined in such a way that a rail is stood about 50cm tall from the natural surface. This height is best for the installation.
Therefore the 1st rail post is offset about 50cm from the intersection of the natural surface and the design slope gradient
However the landform on the design drawing is different from the real one. And so a skilled experienced worker decides the offset by judging the size of the butter slope and the actual landform. This 1st rail post decides the workmanship of the slope stake installation that the materials are kept to minimum and would not interfere with constructions.

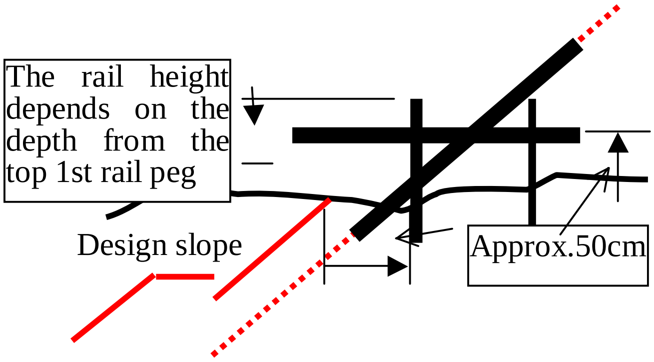


Fig. 3: Basic concept of the slope stakes

2.2.2 Manual calculation is required in the field

After an elevation of the 1st rail post is determined (Fig. 2), there is a need to calculate the rail and slope rail. The elevation of the rail is determined by the height from the top of the 1st rail post. This elevation is not known until the 1st rail post is set up, and so the calculation is required right there in the field. If the design slope does not intersect with the rail, the slope rail cannot be set up.
When the butter gets complex, an inexperienced surveyor cannot put the slope rail at one try. What he does is the trial and error calculation, which decides the height from the 1st rail post. Computation time increases as the butter gets complex, and miscalculation is resulted.
Further, some stakes may not be set up, for example in firm ground. Although there is no statistical data, people who had done told that 10 to 20% could not have been placed. In this case, they have to redo the pre-calculation and may fail to progress the work if the worst happens.
Surveyors are so busy operating instruments and calculating that they have almost no time to rest.

2.2.3 Accuracy

Accuracy of the slope stake installation is determined by the difference between the slope rail and a line of the design slope gradient. Workers use this slope rail, so the outcome depends on the slope rail.

According to the figure 2, the instruments that affect the accuracy are the Total Station, (level), surveying tape, level vial and slant vial. We do not know which parameter affects the accuracy.
It is because workers are too much obsessed with the accuracy check, and there is no data accumulation in the past since no tolerance level is provided.

2.3 The flow of the development

Our goal was to eliminate the pre-calculation and the manual calculation in the field.
If these two are eliminated, the slope stake installation becomes possible for anyone who has no experience. This should also have an effect on reducing the time to set up stakes since manual calculation will not be needed.
Regarding the accuracy, we aimed to simplify the checking system as the first step.

- The coordinate calculation of the 1st rail post from the design data and its algorithm
- The rail/slope rail calculation algorithm
- The inspection algorithm

2.3.1 <u>The coordinate calculation of the 1st rail post from the design data and its algorithm</u>

The 1st rail post has to be offset about 50cm from the intersection of the natural surface and the design slope gradient as shown in the figure 3.
There are restrictions when we think about algorithm. Surveying instruments have lesser CPU and memory compared with PCs. It is simply impractical for the surveying instrument to hold all the design data that the CAD system on the PC can and calculate as fast as it does. In addition, even if a surveyor calculates the intersection point and decides the offset, it is often the case that the actual landform is different from the one on the design drawing.
We, therefore, decided to make up a “virtual natural elevation” that serves as the natural surface and not to enter the data of the landform into the instruments. (See Figure 4) A

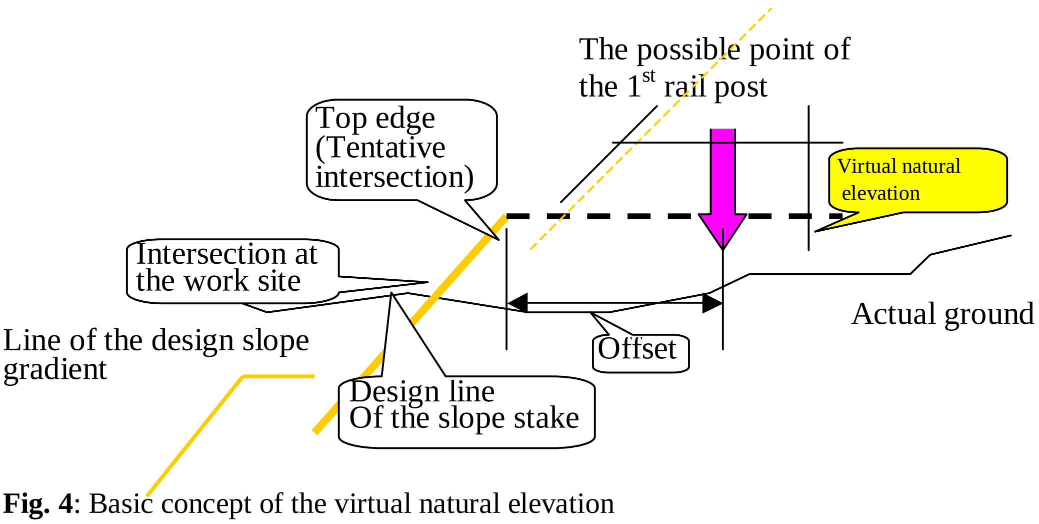


Fig. 4: Basic concept of the virtual natural elevation

The virtual natural elevation needs an initial value. The value is assumed to be at the top of the design slope where you want to set up the slope stakes.

The “top edge” of the design line is sticking out too much in the figure 4. If nothing is done, the 1st rail post would be set up far away from the slope rail owing to the offset calculated from the initial value.
The 1st rail peg will be guided to the possible point on FIG-4 using TS and Prism.
When the Prism comes close to the possible point, and when TS measures an elevation of the current prism position while staking out, the elevation becomes the real natural elevation.
When the difference between the Virtual natural elevation and the measured elevation exceeds a tolerance, the initial value will be substituted to Virtual Natural Elevation from the measured elevation.
Then intersection calculation will be done again between the design slope and the substituted elevation. At the same time, the possible point will also be recalculated using the offset and intersection point.
The position of the possible point in FIG-4 would be changed before staking. The substitution will be repeated until the difference is not over the tolerance. The algorithm is given in FIG-5.

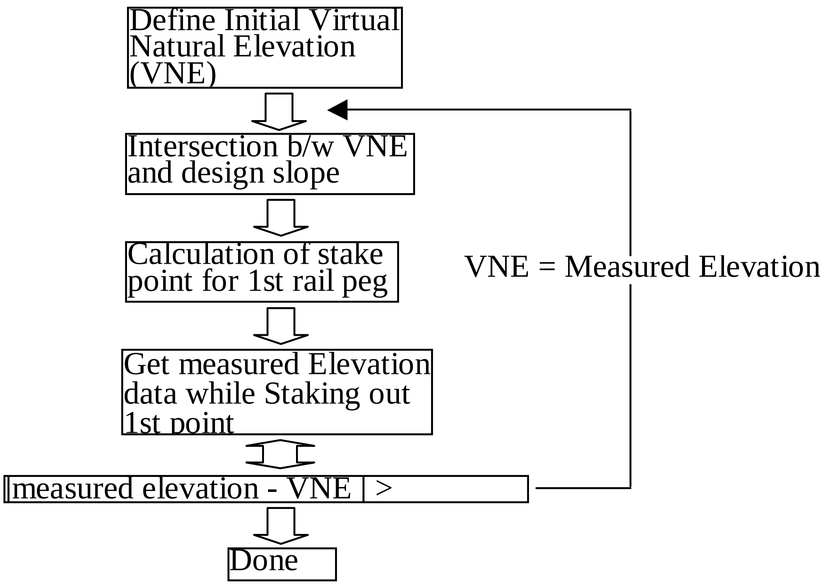


Fig. 5: algorithm

Even if the possible point is not suitable, this algorithm can re-calculate the point before the 1st rail peg is staked.

2.3.2 The rail/slope rail calculation algorithm

As shown in the figure 3, the elevation of the rail depends on how much it is lowered from the top of the 1st rail post. Once it is determined, the intersection of the rail and the slope rail can be calculated.

We, then, decided to display the rail elevation and the intersection of the rail and the slope rail by entering the length that the rail is lowered from the 1st rail post. We also have the value of the design slope gradient□%, 1:X□ acquired from the design data and displayed on the screen because the slope rail installation is actually done by a slant.
In this way, all they have to do in the field is to enter the length from the 1st rail post, and the rest is calculated by the surveying instrument. It should reduce the time to set the slope stake because the surveyor can then concentrate on the measurement only.

2.3.3 The inspection algorithm

If you measure any point on the slope rail, the instrument displays and records the difference between the value of the design drawing and the measured value by using the design data already saved in the instrument. This enables to verify the accuracy of the existing and the new methods.

3. PRACTICAL APPLICATION

3.1 The way to Compare with the Present Situation

We designed a test site and compared these two methods of old and new. The figure 6 shows the design data.
This experiment was done by one single group of people so as not to make any differences among people.

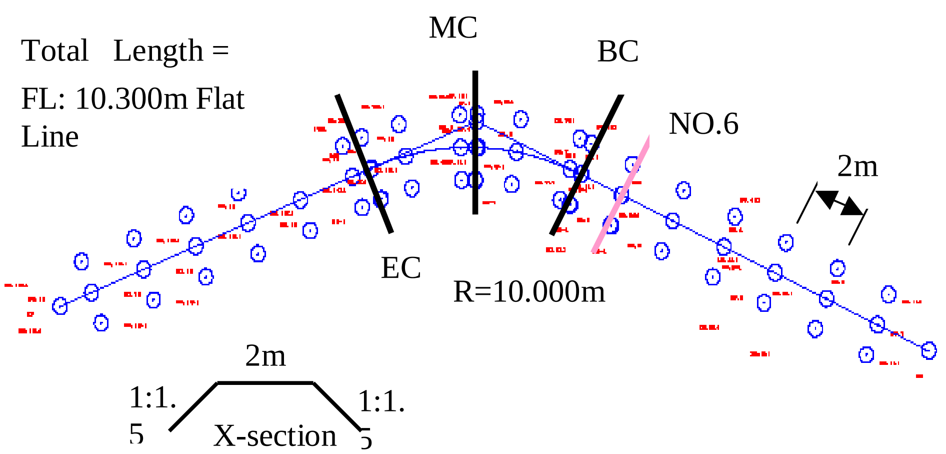


Fig. 6: the design data used in the experiment

We installed the algorithm in the instrument shown in the figure 7.

Fig. 7: TS equipped with the algorithm

The existing method set up No. 6.
Our new method set up No. 6, EC and MC.

3.2 Evaluation

3.2.1 Pre-calculation

The existing method first requires estimating the point of the 1st rail post and then calculates back the direction angle and distance of the point. It takes about 2 hours to do it, but our method requires only entering the design data, so that it takes only 5 minutes.
If we can create the way to enter the design data directly from the CAD system in the future, we will be able to eliminate the pre-calculation completely as we intended at first.

3.2.2 Manual calculation in the field

Our system completely eliminated the manual calculation in the field.
Additionally, we face no difficulty in setting up the stakes in the place where the natural surface is different from the one on the design drawing. The surveyor especially felt the effectiveness of the needlessness of the calculator in the field.

3.2.3 Time

The both methods had only few differences and took 14 minuets to set up the slope stakes.
It is probably because the surveyor took hardly any time to do manual calculation. The test site we picked was almost flat and the design data was simple.
However, if slope surface gets complex, it will take a good amount of time to calculate, which makes differences between the existing and new methods.
The existing system tries to save time by making two people perform calculation and the operation simultaneously, as shown in the figure 2. Even if we increase the workmen to 3, it would not reduce the time drastically. It will only increase the waiting time. Our method,

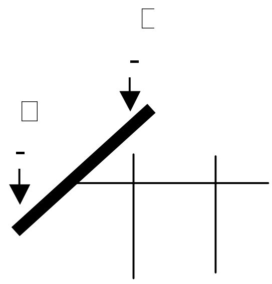
however, need no time for calculation in the field. Therefore as soon as the 1st rail post is set up, the workmen can start on setting the rail and slope rail, which would result in the rapid installation. After this, we need to verify the effectiveness by actually applying this system into work site.

3.2.4 Accuracy

We used this system's verification algorithm to examine accuracy of the two methods. We measured two points on the slope rail that we set up. (See Table-1)

Table 1: Comparison of accuracy between two methods

Measure Points	Chainage	Delta H
NO.6 -1	NO.5+1.953	-0.005
NO.6 -2	NO.5+1.906	-0.004
NO6+1.597(BC) -1	NO.6+1.556	0.007
NO.6+1.597(BC) -2	NO.6+1.651	-0.016
NO.8+1.435(MC) -1	NO.8+1.469	0.005
NO.8+1.435(MC) -2	NO.8+1.565	0.023
NO.10+1.273(EC) -1	NO.10+1.299	-0.016
NO.10+1.273(EC) -2	NO.10+1.311	-0.037



We see hardly any difference with the design slope but the accuracy is about plus or minus 5 cm.

4. CONCLUSION

- Our system enabled inexperienced people to set up the 1st rail post by installing the design alignment data and the "virtual natural elevation" algorithm into the surveying instrument. It is effective for the people who have almost no experience. And it is especially useful when the stakes cannot be set up due to the geological condition.

- The "virtual natural elevation" algorithm was significant since it eliminated the calculation by a calculator.

- This experiment tells that the accuracy of the slope stake installation is between 0.004 to 0.037m. If we investigate the parameter that affects the accuracy, we might be able to develop even easier system.

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BIOGRAPHICAL NOTES

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