# The X-factor of a bike-friendly incline

*Christian ter Braack, student, Hogeschool Windesheim*

*Otto van Boggelen, Fietsberaad*

**City planners have discovered the bicycle bridge. In recent years a number of striking bicycle bridges were opened in different places around Holland. But what makes a bicycle bridge bike-friendly? Christian ter Braack, an intern at Goudappel Coffeng, gathered the criteria in a list and then set out to see if they were being followed, along the way asking cyclists what they thought.**

L. Roos published research on the design criteria for bicycle bridges and bike ramps as early as 1946, when he asked various services and road authorities which demands on footpaths and cycling paths had to be met, including the maximum and optimum slopes. Roos additionally measured the slopes of a large number of bike ramps, particularly those where the cyclist had to dismount or had trouble reaching the top.

Based on this data Roos recommended that a fixed relation be maintained between the height that had to be overcome and the average slope percentage (grade): *average grade = 1 divided by 10 times the height difference* . Many road developers know this rule better in its alternate form: *(horizontal) length of slope = 10 times the height squared (*otherwise written algebraically as L = $10h^2$*).*This is a handy formula to quickly compute the space requirements of the slopes to new tunnels or bridges. Furthermore, the rule can be easily adapted to local conditions by replacing the factor “10” with another value. In this context, the X-factor is mentioned later in this article. The ideal bike ramp, according to Roos, has a slope factor 20. An X-factor of 5 corresponds to the steepest bike ramp.

**Physical limitations**

As far as is known, no subsequent research into bike ramps was done until 1984 when Ir. A.J.M. Van Laarhoven, working for the province of Gelderland, conducted deep theoretical research into the desired design of inclines. Based on the physiological limitations of different categories of cyclists (age, sex, among others), he established recommendations for the average grade. Van Laarhoven's research takes into account a number of factors including head wind, air temperature, ambient lighting conditions (compelling use of the headlamp dynamo) and pedalling frequency. Although their approaches differ strongly, their recommendations are in broad measure similar (graph 1). The recommended average grade drops sharply when cyclists have to overcome a larger height difference.
Van Laarhoven also concludes that the slope is allowed to be steeper at the start of the climb than at the end. The reasoning behind this is that the cyclist initially builds up his approach speed in order to overcome the height difference quickly after which a decreasing slope ensures a constant speed and cycling effort. If the height to negotiate exceeds 5 metres, he recommends interrupting the climb with a plateau, allowing the cyclist to catch his/her breath and build up speed for the next rise.

The research done by Van Laarhoven laid the basis for various CROW publications as we know them today: *Tekenen voor de fiets*, 1993 ('Design for the Bicycle', 1993) and *Ontwerpwijzer Fietsverkeer*, 2006 ('Design Guide for Cycling Traffic', 2006).

## Research into the practical aspects

The research internship conducted by Christian Braack in the autumn of 2008 and commissioned by the Cycling Council and Goudappel Coffeng also puts the emphasis, just as Roos did, on the use of bike ramps in practice.

Eleven artificial slopes located throughout Holland were examined and their average and maximum grades were determined by measuring the grades at intervals of 10 metres with a digital level.

In addition Ter Braack observed the behaviour of cyclists and took surveys of cyclists who used the bike ramps (N=128). During observations, special attention was paid to the effort exerted by the cyclist. Lurching from side to side means that the cyclist is having difficulty with the incline, and if the cyclist has to dismount, then the slope is too steep. The survey allowed cyclists to judge the ramps: did they have trouble reaching the top or could the ramp have been made steeper? The scores were converted to figures while a number of characteristics of the cyclist and the bicycle were also recorded.

Two remarks need to be made about the research method as applied in this investigation. Firstly, one has to take into account the fact that cyclists who find the bike ramps too steep are under-represented precisely because many of them would avoid these steep ramps and opt for a different route or mode of transport. This makes the average assessments higher. Secondly, the number of surveys taken per bike ramp is too small to warrant objective statements for specific bike ramps.

## The influence of age and sex

In spite of these limitations, the research offers enough material with which to quantify the influence that various factors have on the assessments of bike ramps. In accordance with expectations, sex and age have a big effect on the score given to a bike ramp. For every age increase of 10 years, the score drops by 0.4 points. Men give on average a score that is half a point higher than women do.

By far the majority of cyclists (85%) have a geared bike – women somewhat more frequently than men, and seniors somewhat more frequently than their juniors. In short, those who have the most trouble with the bike ramps are more likely to have a geared bicycle. But it is not the case that owners of a geared bike rate the bike ramps more positively (even after correcting for age and sex) . Moreover, none of the respondents climbed the bike ramp with an electric bike.

*The age and sex of the cyclist have a large effect on the score given to a slope.*

The key question for developers and policy makers is: does the design of the bike ramp have an effect on the assessment made by its users? As is to be expected, the average score drops when cyclists have to overcome a larger height difference – but this relationship is weak and not significant. A large height difference does not result in a lower score in all cases. Cyclists probably understand that a large height difference is inevitable if a railway or canal needs to be crossed. Another possible explanation is that the disadvantage of a large height difference is compensated by a good design of the slope.

The same is true for the average and maximum grades. On average, the score is lower if the ramp is steeper, but this is not a strong connection.

*The Snelbinder connects the new urban district north of the Waal (the Waalsprong) with the centre of Nijmegen. Notable is the high X-factor and positive assessment by cyclists.*

**The X-factor**

In order to get more grip on the influence of the design on the assessment, a subsequent analysis was done using Roos's formula. For every bridge and tunnel, the X-factor was computed (*horizontal length – or the 'run' – divided by the square of the height difference*). The *Snelbinder* in Nijmegen has the highest X-factor (21) and the *Nesciobrug* in Amsterdam the lowest (3.7).

*Nesciobrug (l) , Amstelwijckbrug (r)*

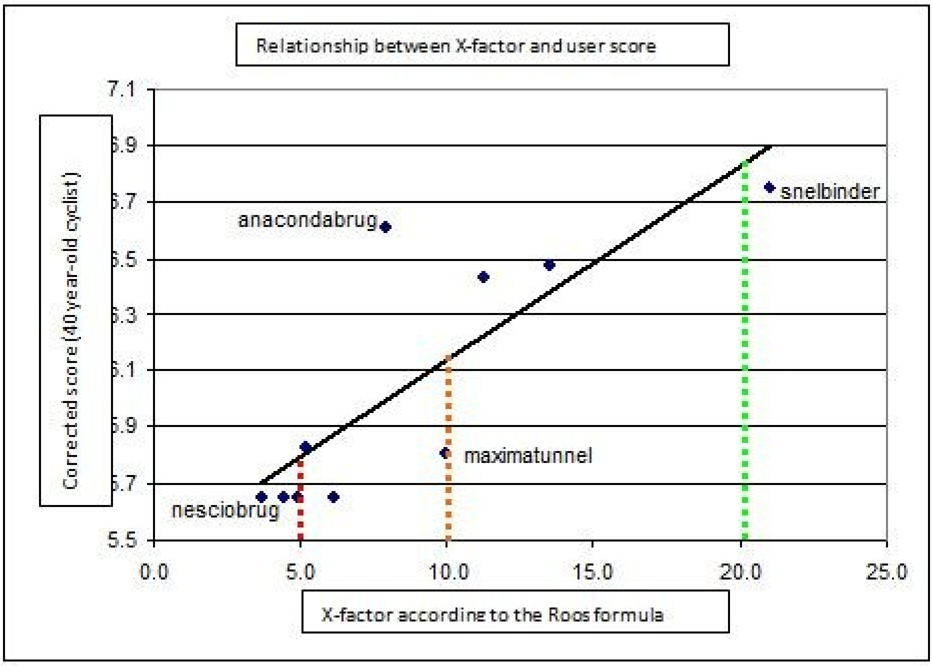
There seems to be indeed a strong correlation between the X-factor and the user's assessment; A larger X-factor correlates with a higher score (see graph 2). Cyclists accept a larger height difference as long as the horizontal length of the slope increases in proportion to the square of the height. This correlation is stronger when one corrects for age and sex. It is also seen that the average score 6 corresponds to an X-factor of 10 – which is confirmation that Roos got it right in 1946 with his recommended equation: *horizontal length of slope = 10 x height difference squared (L = 10h*$^2$*)*. One should note that this is applicable to middle-aged cyclists. Now that the effect of age, sex and X-factor on users's scores is known, one can easily compute the scores for different combinations of these factors (tables 1, 2, and 3). A bike ramp with an X-factor of 10 (corresponding to the recommendation made by Roos), is given an average score of 7 by a 25-year old man, and 4.8 by a woman aged 65. A bike ramp with an X-factor of 20 (corresponding to the ideal slope according to Roos), is given an average score of 7.8 by a 25-year old man, and 5.6 by a woman aged 65.

*Tables 1,2 and 3*

| User score by age and sex, for an X-factor of 10 | | sex | | |
|---|---|---|---|---|
| | | woman | man | average |
| age | 25 | 6.5 | 7.0 | 6.7 |
| | 40 | 5.9 | 6.4 | 6.1 |
| | 65 | 4.8 | 5.4 | 5.1 |

| User score by age and sex, for an X-factor of 20 | | sex | | |
|---|---|---|---|---|
| | | woman | man | average |
| age | 25 | 7.2 | 7.8 | 7.5 |
| | 40 | 6.6 | 7.1 | 6.9 |
| | 65 | 5.6 | 6.1 | 5.9 |

| User score by age and sex, for an X-factor of 5 | | sex | | |
|---|---|---|---|---|
| | | woman | man | average |
| age | 25 | 6.1 | 6.6 | 6.4 |
| | 40 | 5.5 | 6.0 | 5.7 |
| | 65 | 4.5 | 5.0 | 4.7 |



*Graph 2.*

**Detailing**

As described before Roos's formula gives the *average* grade from which it is not possible to make concrete statements about the finer details concerning the slopes based on the survey results. For instance, is it really advisable to interrupt the slope with plateaus in steep sections? Or could the available length of the slope be better utilised to provide a lower grade over the entire length, thus allowing the cyclist to pedal at the same rate? This seems less relevant than the X-factor.

At most of the researched slopes with a difference in height greater than 5 meters, one or more plateaus have indeed been implemented. Sometimes for pragmatic reasons: the plateaus are incorporated in the curves that had to be made to fit the slope in the available space. (*Nesciobrug* in Amsterdam and the *Amstelwijckbrug* in Dordrecht). While in the curves the cyclist can regain his / her breath, before negotiating the rest of the incline.

*In order to fit the Nesciobrug bike ramp in Amsterdam into the available space, a U-curve has been made (left path). Pedestrians on the right path can use the staircase as a shortcut.*

### Integration of the slope

In urban areas it is often difficult to integrate long bicycle ramps into the available space. Several solutions have been applied in practice, such as the U-curve of the *Nesciobrug* in Amsterdam, the S-curve of the *Amstelwijckbrug* in Dordrecht or the spiral of the *Bunnikseweg* bicycle bridge in Utrecht. The solutions are often combined with a short staircase (with bike gutter). The disadvantage of curves built into the bike ramp profile is that they increase the cycling distance.

*Plateaus are sometimes made to conserve space. Cyclist can catch their breath on them, such as shown here in the Amstelwijckbrug in Dordrecht.*

## Four steps towards a bike friendly slope

*Bunnikseweg*

1. Try to avoid differences in height as much as possible. Every rise means extra effort for cyclists, leading to less frequent use of bicycles. Overcoming a difference in height of 5 meters, for instance, requires that a cyclist expend as much energy as is required when cycling half a kilometre on level terrain. Rises can be negotiated through the use of either a bike ramp or a tunnel. For tunnels, smaller differences in height usually suffice. The differences in height can also be tackled by slightly raising or lowering the road itself.

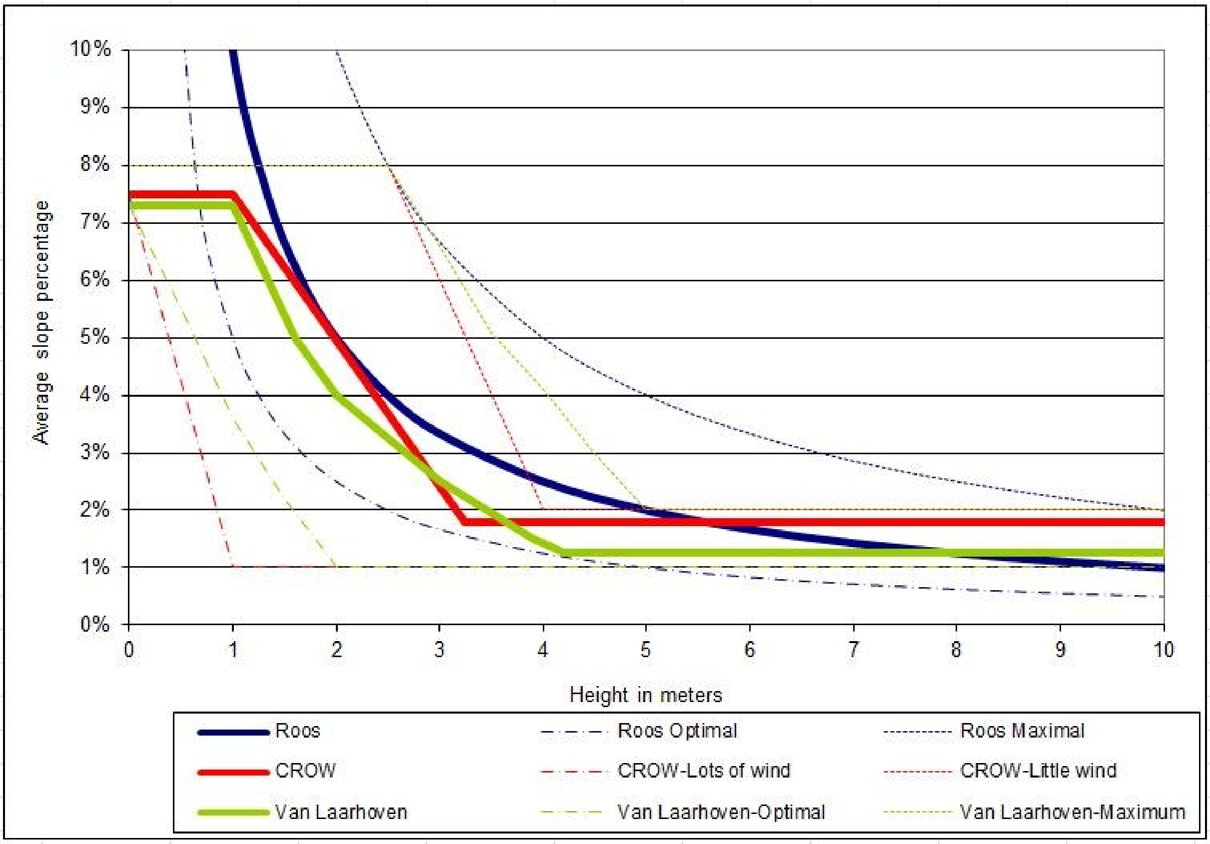
2. Determine the desired length of the slope using the CROW-recommendations or Roos's formula.  Use a value greater than 10 when extra comfort is necessary, for instance in urban areas, areas with many elderly people, or windy areas.

3. Determine if the desired length of the slope will fit in the available space. If not return to step 1 and start anew.

4. Work out the detailed design of the slope. The onset of the slope may be steeper than the aftermath. Consider introducing a plateau when the height difference exceeds 5 metres.

   The *Fietsberaad* website gives a spreadsheet that one can use to calculate both the average grade (step 2) as well as the slope profile (step 4).

## Summary of the various Guidelines for Slopes



*Graph 1.*

There are many similarities between various recommendations for the average grade. All recommendations state that the suggested average grade ( up to a difference in height of 4 to 5 meter) will initially strongly decrease as the difference in height to be negotiated increases. Small differences in height result in large differences in the length of the slope. For instance: A height difference of 1 meter needs a slope of approximately 13 metres. A 4-metre height difference requires a 200-metre slope.

Conversely, if the height difference to be dealt with can be reduced slightly, a shorter slope will suffice.

Height differences greater than 4 to 5 meters hardly result in a decrease of the average grade. This means the length of the slope will increase in proportion to the extra difference in height. But because the average grade remains low, the extra difference in height will also make a big difference in this case.

Van Laarhoven’s recommendations and those of the CROW resemble each other the most - which is not surprising, since the CROW recommendations have been derived from Van Laarhoven’s. However it is notable that CROW recommends a slightly steeper grade (1,8 %) at  greater height differences (> 4 meter) than Van Laarhoven (1,25%).

The attraction of Roos’s recommendation is that it can be described by a simple mathematical formula (length of slope = 10 x height$^2$).

Roos’s recommendations resemble those of the other two in the intermediate regime corresponding to a height difference of 1.5 to 6 metres.

For lesser height differences, Roos’s slopes are much steeper and in the case of large height differences they are slightly less steep.