Budownictwo i Architektura 19(2) 2020, 111-120
DOI: 10.35784/bud-arch.1621

Received: 24 April 2020; Revised: 04 July 2020;
Accepted: 12 July 2020; Avaliable online: 28 August 2020

Orginal Article

Geometry of the cycling track

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The paper describes the problems related to shaping of the geometry of the cycling track. The method of selection of the angle at the track curve is presented. Issues related to the selection of the appropriate transition curve and the superelevation section along the transition curve are presented. Reference to the recommendations presented in the literature and scientific papers has been made. Special attention to the need of consideration of the subjective feelings of the cyclist is paid. The paper describes the guidelines of the International Cycling Union (UCI) on shaping the geometry of the cycling track.

Keywords: geometry of cycling track; track cycling; transition curve

1. Introduction

Cycling tracks are facilities where track cycling competitions are held. They are oval in shape, with a characteristic significant inclination of the track on a horizontal curve often reaching 45°. During the competition, there are two types of races on the cycling track: sprint and endurance. Fig. 1 shows a view of the Olympic velodrome in London.

Fig. 1. View of the Olympic Velodrome in London; author of the picture: Tom Green

Among the scientific articles published in recent years on track cycling, the most dominant are those on mathematical modelling of the cyclist's movement on the track, improving the aerodynamic position of the cyclist on the bike, improving the geometry of the bike, improving training methods and improving indoor conditions (such as temperature, humidity, ventilation) to enable athletes to improve their performance. The article [1] presents the results of measurements of air speed and turbulence during a simulated chase race taking place on the cycling track. It describes how the resistance and turbulence of air changes during the ride of one cyclist after another. In the publication [2], the authors presented a continuous mathematical model for the simulation of cycling on a track, which includes calculated angles of slip and steering wheel turns. Model validation was provided by data from a power meter, wheel speed and timekeeper obtained from two different studies and from eight athletes. In the paper [3] the authors described a model which is useful for the analysis of cycling track physics and can be used to predict performance depending on the bike efficiency, type of tyre and conditions on site, in a racing scenario. In [4] the author describes the way of designing the architectural structure of the cycling track in London, in such a way as to provide increased temperature and ventilation for the participants to compete, while minimizing these factors for the public. The article [5] analyses the current knowledge on the reaction to acute or chronic exposure to altitude associated with single and multiple sprints, among others in track cycling. It is only a small extract from current scientific topics in track cycling. However, there are few publications on track geometry construction in the literature. Physical, psychological and equipment aspects are analyzed in detail. Many scientists strive to improve and refine known methods, in line with the idea of small profits, enabling cyclists to beat more records. This article collects guidelines for cycling track geometry and presents directions for further research to improve sports performance, but in the new variant – by shaping track geometry (an approach rarely seen in the scientific literature so far).

As it was written in [6], the text devoted to the velodrome for the London XXX Olympics 2012: *the exact geometry of the cycling track is a strict secret.*

In recent years a number of cycling tracks have been built around the world. The most important of these facilities (tracks for the Olympic Games and the World Championships) were designed by two constructors: Ronald Vincent Webb and Ralph Schürmann.

The article presents problems related to the selection of cycling track geometry, discusses the guidelines of the International Cycling Union (franc. UCI: Union Cycliste Internationale), describes and critically assesses the opinions presented in [7].

2. International Cycling Union (UCI) Guidelines

The guidelines of the International Cycling Union concerning the geometry of the cycling track are quite scarce and leave considerable freedom in the choice of solutions for the designer of the object. According to document [8] (translated into Polish in [9]), the construction of the cycling track itself is entirely the responsibility of the designer: The stability and resistance of the materials and fixings which make up the structure of the velodrome shall meet the legislation regarding construction and safety of the country in which it is built and shall take account of specific geological and climatic conditions. These elements, along with general compliance of the construction and construction materials with technical standards and good practice, remain the exclusive responsibility of (…) engineers (…).

The UCI guidelines [8] for the category 1 facility (thus the track for the Olympic Games and the World Championships) specify:

- the length of the track: 250 m,

- the width of the track: 7 – 8 m,
- horizontal curve radius: 19 – 25 m,
- minimum safety speed: 85 – 110 km/h.

Moreover, in [8] important data from the point of view of track geometry are presented:

- the inner edge of the track shall consist of two curves connected by two parallel straight lines,
- entrance and exit of the curves shall be designed so that the transition is gradual,
- the banking of the track shall be determined by taking into account the radius of the curves and the maximum speeds achieved in the various disciplines,
- the width of the track must be constant throughout its length,
- at any point on the track, a cross section of the track surface must present a straight line.

This is a series of generally formulated guidelines, thanks to which the designer of the object has considerable freedom in choosing the transition curve and the superelevation section on the horizontal curve of the cycling track. Fig. 2 shows a diagram of the construction of the cycling track. In the guidelines [8], it is given additionally:

- the length of the track shall be measured 20 cm above the inner edge of the track (the upper edge of the blue band). This line is called the “track measurement line” and is black on a light or white background or white on a dark background,
- a red line, known as the “sprinters’ line” shall be marked out 85 cm from the inner edge of the track,
- a blue line, known as the “stayers’ line” shall be drawn at one third of the total width of the track or 2.45 m (whichever is the greater) from the inner edge of the track,
- the width of the infield (blue track) must be at least 10% of the track width. The slope of the infield is between 6° and 12°,
- the minimum width of the safety zone including the infield is 4 m for 250 m tracks,
- a fence at least 120 cm high must be made along the inside edge of the safety zone,
- the outside edge of the track is to be surrounded by a safety fence with a total height of 90 cm.

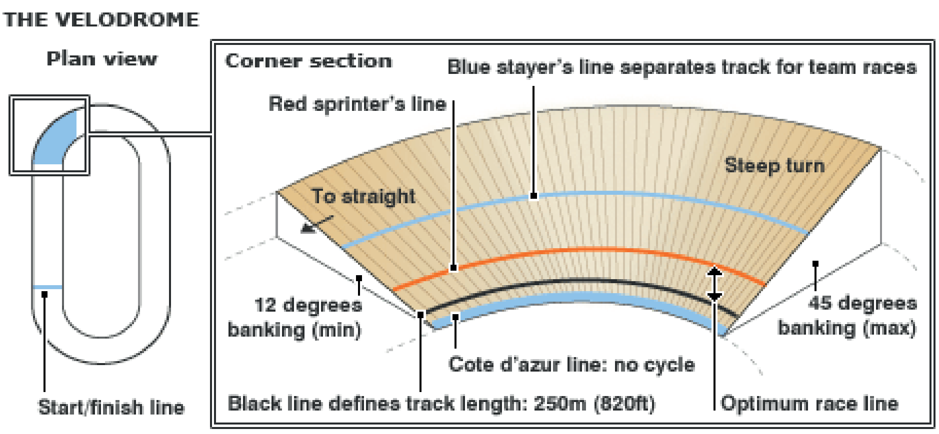

Fig. 2. Scheme of the construction of the cycling track; source: www.bbc.com, access: 20.08.2015

It is worth noting the necessity of very precise track length measurement, after point 3.6. 074 in [8]: the tolerance of flatness for the track surface shall be 5 mm over 2 metres, after [10] (page 118): track length is measured with an accuracy of 0,005 m and in [11] (page 72): if the track length exceeds 250 m by more than 0,0012 m, the track will be rejected by the controlling UCI representative (it should be stressed that track cycling times are measured with an accuracy of one thousandth of a second).

3. Construction of the track on a horizontal curve

Using the relation given in [10] (page 119), the slope of the track in the horizontal curve is calculated from the formula:

$$\tan \alpha = \frac{V^2}{gR}\ [°] \tag{1}$$

where: V – design speed, $g = 9{,}81$ m/s^2 – acceleration value, R – horizontal curve radius of the cycling track.

For category 1 track, the size of the gradient at which the cyclist will move on a horizontal curve in a position perpendicular (forming a right angle) to the track surface in a range is obtained:

$$\alpha = 66{,}3° \div 78{,}7° \tag{2}$$

Fig. 3 shows a schematic diagram of the forces during horizontal curve riding. During the ride, the cyclist is able to tilt the bike in either direction. Therefore, the friction of the tyre against the track surface should be considered. In [10], it was proposed (based on the experience of Foerster) that the cyclist should have an optimal, safe inclination of up to 30° in both directions without fear of slipping. This issue is presented in fig. 4. Because:

$$\alpha - 30° = 78{,}7° - 30° = 48{,}7° \approx 45° \tag{3}$$

it can be considered that the inclination of the horizontal curve on most of the cycling tracks has been chosen in the way given above.

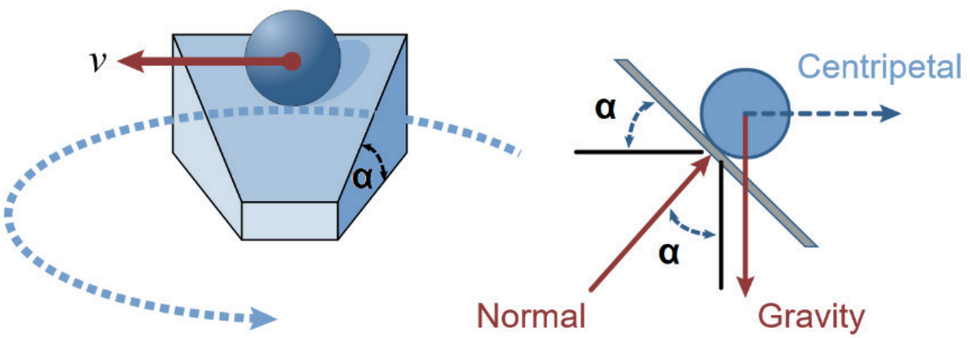

Fig. 3. Diagram of force applied to a cyclist when riding in a horizontal curve; source: en.wikipedia.org, accessed 20.08.2015

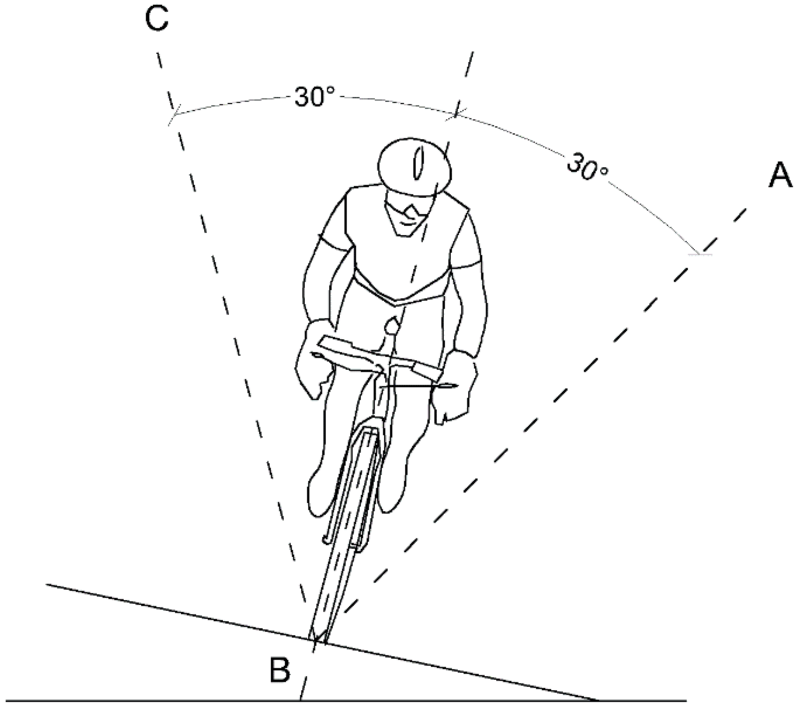

Fig. 4. Permitted and safe inclination of the cyclist on the track to a position within AB or BC; source: own elaboration

Ronald Vincent Webb (Australian Cycling Track Designer, designer of tracks for the 1988 Seoul XXIV Olympics, the 2000 Sydney XXVII Olympics, the 2004 Athens XXVIII Olympics, or the XXX Olympics in London in 2012), in his article in [11] (pages 70 – 73) noted that the above considerations about riding in a horizontal curve are fully consistent for four-wheeled vehicles, e.g. cars, because they are then subjected to forces like in Figure 3, where only the frictional force is omitted. Next, the designer notes that unfortunately, through the years, many cycle tracks have been built in this style. The problem arises because a competition cyclist is on two wheels, and the rider's centre of gravity, balance and friction will be constantly changing, due to aggressive riding or sudden changes of direction within a large field of competitors. Speeds will vary accordingly and sometimes he or she will be riding slowly. The above remarks of Ronald Webb are shown in fig. 4, where the cyclist can be seen leaning to the left of the centre of gravity axis of his bike because of the vigorous pressure on the pedals. This is a frequent phenomenon among racers on the track, so it cannot be omitted when considering its geometry.

Fig. 5 shows an example of a cross-section through the track in a straight section and in a horizontal curve. Fig. 6 shows an example of a cycling track geometry modelled in Autodesk AutoCAD 2015 (educational license).

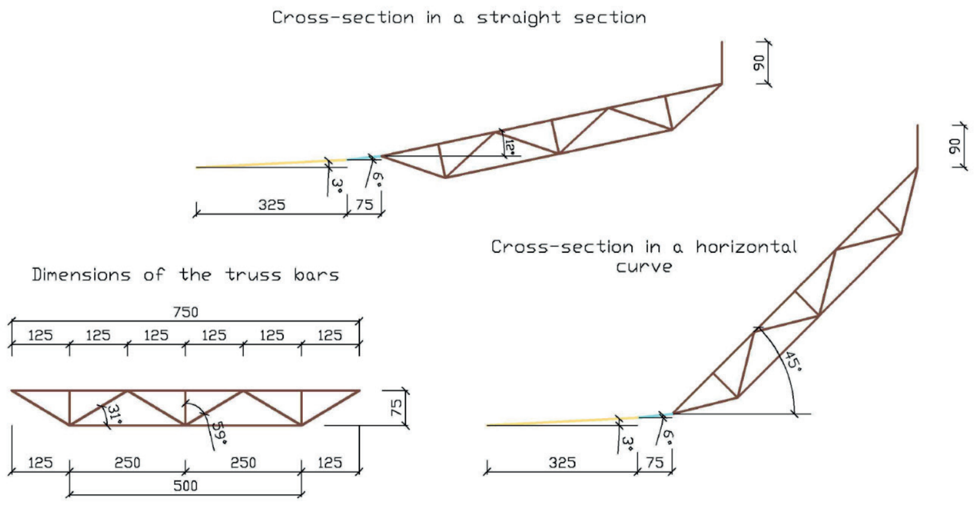

Fig. 5. Cross-section through the exemplary track in a straight section and a horizontal arch; source: own elaboration

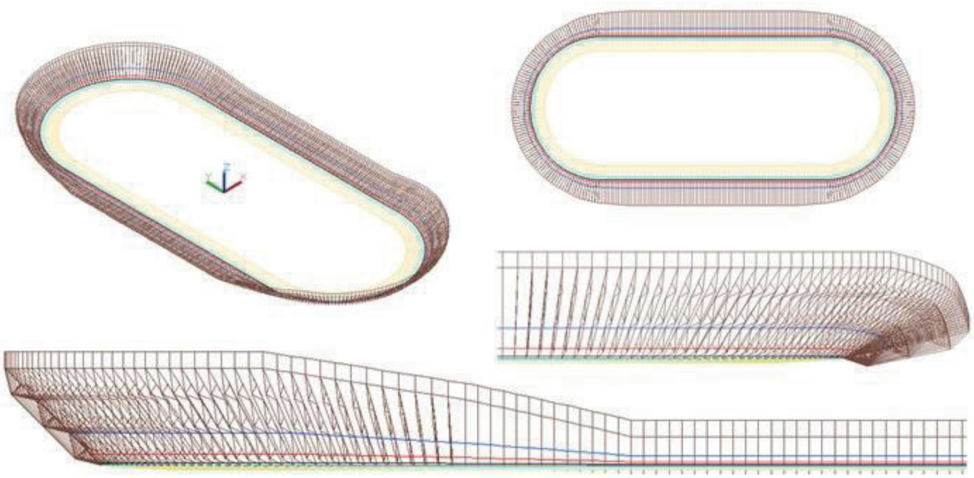

Fig. 6. Cycling track geometry designed in Autodesk AutoCAD 2015 program (educational license); source: own elaboration

4. Cycling track transition curve

The issue of designing the geometry of the cycling track is complex. The secret of the success of famous velodrome designers Ronald Webb and Ralph Schürmann is the right choice of transition curve and superelevation section. By adjusting the vertical inclination of the subsequent parts of the transition curve, the construction of the track can be improved, increasing the cyclist's riding efficiency and thus enabling athletes to improve their performance. In order to modify the vertical geometry of the track accordingly, it is necessary to have experience in this type of design and an appropriate set of data, both based on measurements of the cyclist's lap time, the value of the centrifugal acceleration acting on the cyclist during ride on a horizontal curve, or insight into the measurement of the power generated during the lap, but also taking into account the subjective feelings of the cyclist concerning the comfort of riding when passing from a straight section into a horizontal curve.

It is worth noting that when designing car and railway roads, the transverse slope of the road changes over a long distance, in a rather slow way, while on the cycling track the change takes place over a short distance by a value often exceeding 30°.

In the article [7], the authors analysed the construction of two cycling tracks: the Olympic track in Beijing (where four Olympic records were broken; constructed by Ralph Schürmann) and the one located in the Chinese Sports Institute in Nanjing. They considered the minimization of the rider's time during the 200-metre time trial to be the reference point for the calculation. They suggested using the mathematical model of the track in MATLAB to optimize the slope angles in the horizontal curve. The calculations of the authors show that after applying the proposed solutions, 0.021 s can be saved during the ride. Additionally, the scientists were critical of the existing objects: *Both Beijing cycling track and Nanjing cycling track are praised by athletes, but there still exist some problems (...) caused by inappropriate superelevation runoff models for these tracks.* It should be stressed, however, that there are also other competitions taking place on the track, not just the 200-metre time trial, which the authors considered in their work. The researchers found that *less vertical curvature values correspond to less riding time.* The UCI guidelines and the course of action for determining the slope of the track on a horizontal curve are presented above. By decreasing the slope value, the designer will also have to reduce the speed of minimum safety, which may lead to some limitations when carrying out some of the competitions on the track. It seems that the authors omitted this fact in their considerations. Moreover, they did not take into account the physical characteristics of the riders, which is questionable. When trying to break a record where the thousandths of a second are decisive, the component of the result corresponding to the human factor is very important, if not most important.

A proposal to solve the geometry of the cycling track in the form of a transition curve as a clothoid, and the superelevation section shaped in a straight line (linear increase in superelevation along the length of the transition curve) is presented in [12].

Fig. 7 shows a screenshot of a presentation by Hopkins Architects (responsible for the entire London velodrome construction) entitled "Track Record", which shows a comparison of the shape of the tracks designed by Ralph Schürmann and Ronald Webb. Schürmann's tracks are narrower and longer (the blue line in fig. 7), giving preference to sprinters who have more time to overtake their rival in the longer straight sections (after exiting the horizontal curve, where it is ineffective to overtake because there is a greater distance, the rider has a longer straight section to the finish line). Webb's track is more oval (the red line in fig. 7), which gives better conditions for breaking time records, because when comparing the speed of a rider in a straight section and a horizontal curve it can be observed that the rider achieves higher speed in the area of horizontal curves of the track than in straight sections.

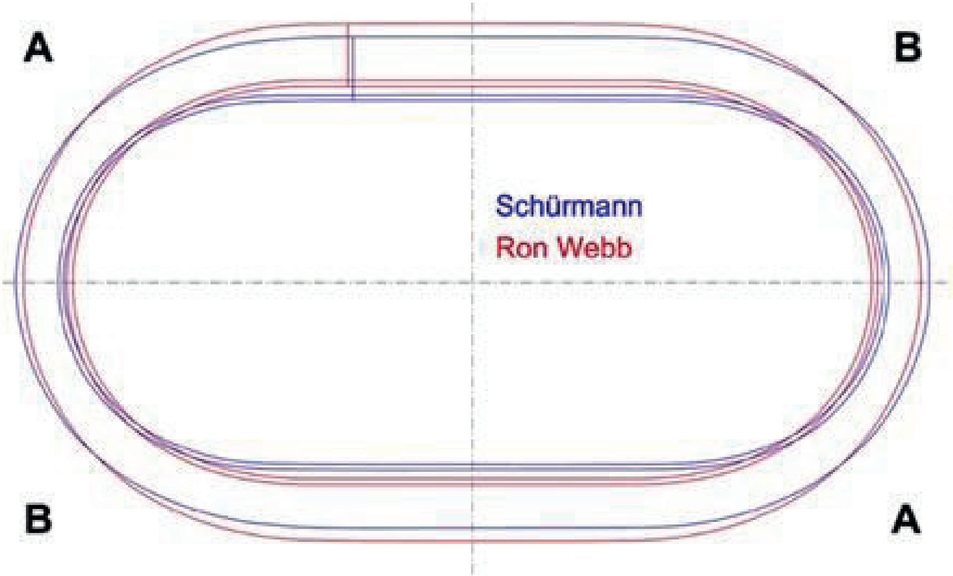

Fig. 7. Comparison of the shape of cycling tracks according to Ralph Schürmann and Ronald Webb; source: screenshot of a presentation by Michael Taylor (Hopkins Architects) entitled Track Record, registered on 18.01.2013, link to the film: https://vimeo.com/59175243, accessed on 20.08.2015.

It is also worth noting the letters A and B in Fig. 7. They show the differences in track slope angles in these places. The part of the horizontal curve marked with the letter A is situated lower than the part indicated with the letter B. As it was written in [6], *the track in the London Velodrome does not have the usual reflection symmetry that can be found in buildings. If the track was built in half lengthwise, the two halves would not match. The track does have rotational symmetry. The slope of the track going into and out of the turns is not the same. This is simply because the cyclist always moves the same way around the track, and go shallower into the turn and steeper out of it.*

5. Summary

The designer has the ability to change the angles that form transition curves and can allow for a smooth transition from steep curves down into smaller angles on straight sections. However, any change of angle must still be governed by laws of physics. At every point and at every angle, the track must be capable of handling the rider's speed and friction. The intention is to shape the track in such a way that a cyclist who rides out of a horizontal curve and enters a straight section has no difficulty in maintaining his line of riding, without the need for additional steering control of the bicycle and can actually benefit greatly from the transition from a horizontal curve to a straight section.

When designing the geometry of the cycling track, the following points must be considered:

- type of transition curve,
- type of superelevation section on the length of the transition curve,

- finding the interaction between the transition curve and the superelevation section in relation to the bicycle as a single-wheeler (a difficult task in comparison with designing car or rail roads, where the vehicle rests on a minimum of four wheels, where the issue of vehicle deviation from the direction perpendicular to the driving surface can be omitted),
- variable position at the entrance and exit height of the horizontal curve of the cycling track.

It will be useful to collect data from the competitors themselves in order to select the above mentioned factors properly. Their feelings and suggestions while riding may significantly improve the solution. Riding in a horizontal curve with an inclination of about 45° requires considerable courage from the cyclist. During the ride an unbalanced centrifugal acceleration affects them. This is the subjective feeling of each competitor. Therefore, it can be concluded that there is no universal track where records in this sport will certainly be achieved.

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