Alignment design for Citybanan in Stockholm

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Abstract

The Western Main Line into Stockholm Central Station was brought into use in 1871 with 10 trains per day. Nowadays, there are more than 500 trains per day on the twin-track between Stockholm Central and Stockholm South, and there is a demand for even more trains. Hence, Banverket (the Swedish National Rail Administration) is planning for a new twin-track railway, Citybanan, through central Stockholm. The capacity will increase with 24 to 30 trains per hour in each direction. All types of trains (commuter, regional, Intercity and freight) will benefit from the increase in capacity.

A feasibility study for the 6 km long tunnel railway was conducted during 2002-2003. Detailed design started in 2004 and the construction work is scheduled to start in 2006 and finish in 2011.

The tracks will be constructed with UIC60 rails, concrete sleepers or slab track, and high-quality elastic rail fastenings. The new railway is expected to survive several generations of signalling systems. Hence, the alignment will constitute the binding constraint for permissible train speeds, both in the short and long term. This is the reason why various alignment options were calculated in detail (including all S&C work) and permissible train speeds were quantified in detail at the feasibility study stage.

This paper presents the track standards from Banverket and the general approach in alignment design of Citybanan. It describes the criteria adopted for locations where margins exist to the minimum requirements, highlights certain detailed layouts and comments on a draft CEN standard for alignment design. Finally, the paper discusses the relevance of alignment expertise employed in the early planning stages of a railway project.
Keywords: Commuter trains, feasibility study, alignment design, CEN standard.

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1 The rail network in Greater Stockholm and track configuration for Citybanan

Stockholm Central Station (km-post 0) is the most important railway hub in Sweden. North of Stockholm C, there are four main tracks leading to the junction Tomteboda, where four tracks continue northwards towards Uppsala and Arlanda airport (East Coast Main Line), and two tracks diverge westwards towards Västerås (Mälar Line). There are plans for a quadrupling of the Mälar Line.

South of Stockholm C, there are only two tracks leading to Stockholm South (km-post 2). From Stockholm S, there are four tracks to Årsta (km-post 7), where two tracks for Nynäs Line deviate from the four tracks of Western Main Line. The Western Main Line has four tracks down to Järna (km-post 48) and continues southwards with two tracks only.

The twin-track between Stockholm C and Stockholm S was brought into traffic 1871 with 10 trains per day. Nowadays, there are more than 500 trains per day on these tracks, and there is a demand for even more trains.

Hence, Banverket (the Swedish National Rail Administration) is planning for a new twin-track railway, Citybanan (City Line), from Tomteboda, through tunnel under central Stockholm and down to Stockholm S. A new fly-over will be built at Årsta to shift the two slow tracks from Citybanan to a position between Fast Up Track and Fast Down Track. Citybanan will mainly carry commuter trains and will increase the capacity through Stockholm with 24 to 30 trains per hour and direction. More pathways on the existing tracks will be available for Intercity, regional and freight trains.

There are two new stations along the route: Odenplan and Stockholm City. Both stations will be connected to the metro, and Stockholm City will be connected to the existing Stockholm Central Station as well. Due to heavy passenger flows and long dwelling times at Stockholm City, this station will be provided with four platform tracks already in the first phase of operation. When the capacity of Citybanan needs to be increased from 24 to 30 trains per hour and direction (Phase 2), the stations Odenplan and Stockholm South will be provided with four platform tracks as well, see Figures 1 and 2.

There will be a pair of crossovers between all stations, and additional crossovers between the two inner tracks at the 4-track stations. Furthermore, due to severe capacity constraints on the Mälar line, Citybanan will be provided with a third track at Tomteboda. The function of the third track is to enable commuter trains to/from the East Coast Main Line to pass commuter trains waiting for train free path on the Mälar Line.

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long term. This is the reason why various alignment options were calculated in detail (including all S&C work) and permissible train speeds were quantified at the feasibility study stage.

No changes in the alignment will be required unless the rock engineers, geotechnical engineers or structure engineers in their detailed design find reasons for a modification of the borders of the available terrain corridors for the tracks.

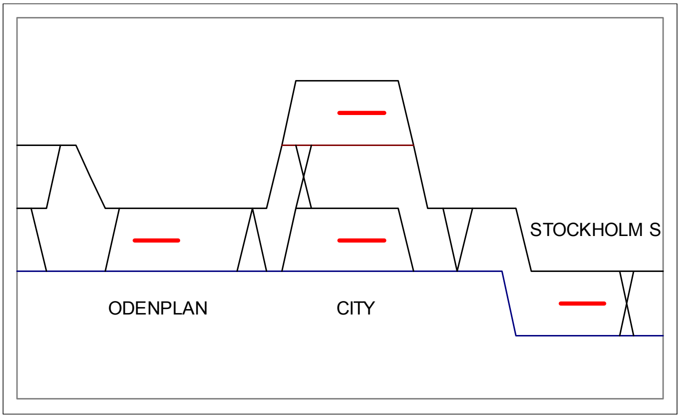

Figure 1: Track configuration for the tunnel portion of Citybanan, Phase 1.

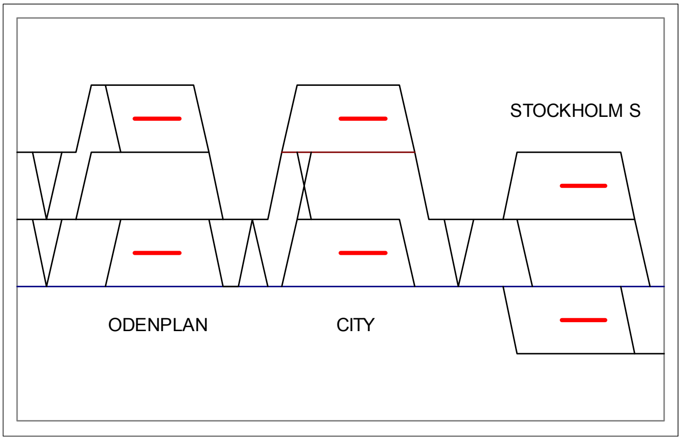

Figure 2: Track configuration for the tunnel portion of Citybanan, Phase 2.

2 Swedish alignment standards and Swedish UIC60 turnouts

In the Swedish track standards, there are three classes of vehicles. Standard vehicles are classified as Category A. Vehicles with track-friendly running gear (radial steering bogies) constitute Category B. Vehicles with track-friendly

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running gear and body tilt systems (tilting trains) constitute Category S. A summary of various (exceptional) limits is presented in Table 1.

Table 1: Certain limits in the alignment design (Source: [1]).

	Category A	Category B	Category S
Max. cant	150 mm	150 mm	150 mm
Max. cant deficiency	100 mm	150 mm	245 mm
Max. cant gradient	1:400	1:400	1:400
Max. rate of change of cant	46 mm/s	55 mm/s	69 mm/s
Max. rate of change of cant deficiency	46 mm/s	55 mm/s	79 mm/s
Max. instantaneous change of cant deficiency	100 mm	100 mm	100 mm
Max. vertical acceleration	0.48 m/s^2	0.48 m/s^2	0.48 m/s^2
Min. vertical radius at a turnout	5000 m	5000 m	5000 m
Min. vertical radius at a superelevation ramp	5000 m	5000 m	5000 m

The concept of virtual transitions (where transition curves are missing) is not used in Sweden, see [2] for a discussion of the relevance of virtual transitions. However, an instantaneous change of cant deficiency of 100 mm is permitted only for train speeds of 100 km/h and lower.

Swedish UIC60 turnouts have tangential switch geometry and consist of a circular curve from the stock rail joint to the heel of the turnout, see Table 2. Two exceptions are the 1:15 and 1:27.5 turnouts, where a short straight is introduced at the heel of the turnout.

Table 2: Swedish UIC60 turnouts (Source: [3]).

Turnout type	Radius	Permissible speed	Comments
1:9	300 m	50 km/h	Standard turnout
1:12	500 m	65 km/h	Standard turnout
1:14	760 m	80 km/h	Standard turnout
1:15	760 m + straight	80 km/h	Special type for crossovers at small track distances
1:18.5	1200 m	100 km/h	Standard turnout
1:26.5	2500 m	130 km/h	Standard turnout
1:27.5	2500 m + straight	130 km/h	Special type for crossovers at small track distances

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3 Design criteria for alignment design

The design speed for Citybanan is 80 km/h for Category A trains, for which the minimum requirements is fulfilled along the whole route. The interesting question is how to handle situations where the available terrain corridors, as defined by architects, rock engineers and structure engineers, allow margins to the minimum requirements.

Many railway companies have a hierarchy of limits (exceptional limits, normal limits, preferred limits) in order to persuade alignment engineers to design track layouts with margins to the exceptional values. Such margins result in layouts generating lower track forces and better passenger comfort, or may be used for increased permissible speeds. Hence, a recent draft standard from CEN [4] states that recommended limits for rate of change of cant and cant deficiency, respectively, should be 10% lower than the exceptional limits. Since equilibrium cant increases with train speed in the power of two, and the sum of the rates of change of cant and cant deficiency increases with speed in the power of three, the draft CEN standard gives a very small margin (3.2%) for increased train speeds.

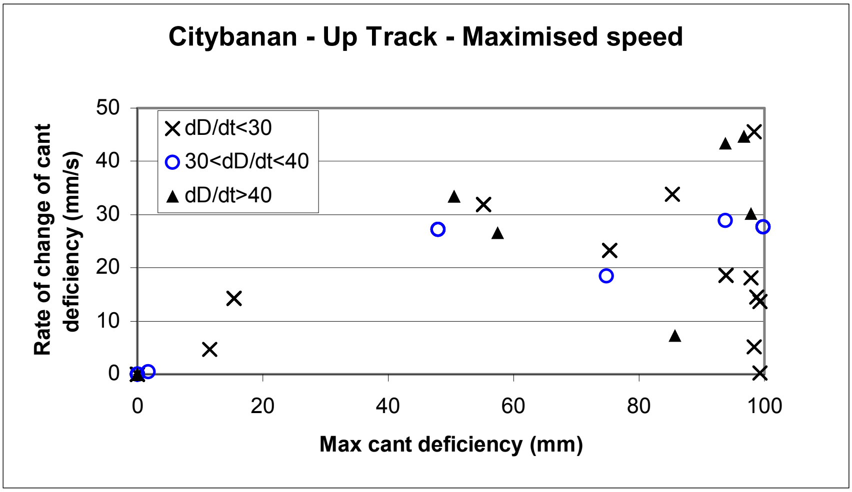

Figure 3: Cant deficiency, rate of change of cant deficiency and rate of change of cant (dD/dt) for the Up Track and a maximised speed profile.

For Citybanan, an alternative approach is used. Wherever possible, the alignments are prepared for a train speed of 100 km/h for Category A trains and 110 km/h for Category B trains. (The alignments are prepared for higher train speeds than 100-110 km/h outside the tunnel portion of Citybanan.) A theoretical justification for this approach is published in [5].

The limit for rate of change cant (46 mm/s) gives a maximum cant gradient of 1:480 for train speeds of 80 km/h, and 1:600 for 100 km/h. On Citybanan, the cant gradients are lower, normally in the range 1:1000 - 1:600. In Phase 1, five superelevation ramps are as steep as 1:550 - 1:500, and in Phase 2 only three.

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Turnouts are placed on straight track wherever possible. Where a turnout has to be placed on a curve, such a curve has been designed with a radius of 1200 m if possible, thus enabling straight 1:18.5-turnouts to be used (using the turnout curve for the through track, and the straight track as the diverging track). This approach reduces the number of tailor-made spare parts.

Even though an instantaneous change of cant deficiency of 100 mm is allowed according to Swedish track standards, such changes are used as rarely as possible. In certain cases, efforts has been made to arrange the change of cant deficiency as a reduction from 100 mm to nil, rather than an increase from nil to 100 mm. (Experience has shown that that a jerk reducing lateral acceleration is less uncomfortable for passengers than a jerk of the same magnitude that increase lateral acceleration [6].)

Turnouts where trains will frequently run through the diverging track are of type 1:18.5, resulting in an instantaneous change of cant deficiency of 63 mm. Alternatively, these turnouts may be used at 100 km/h operation.

Maximum gradient will be 3.0% and minimum vertical radius 5000 m (with two exceptions of 3000 m).

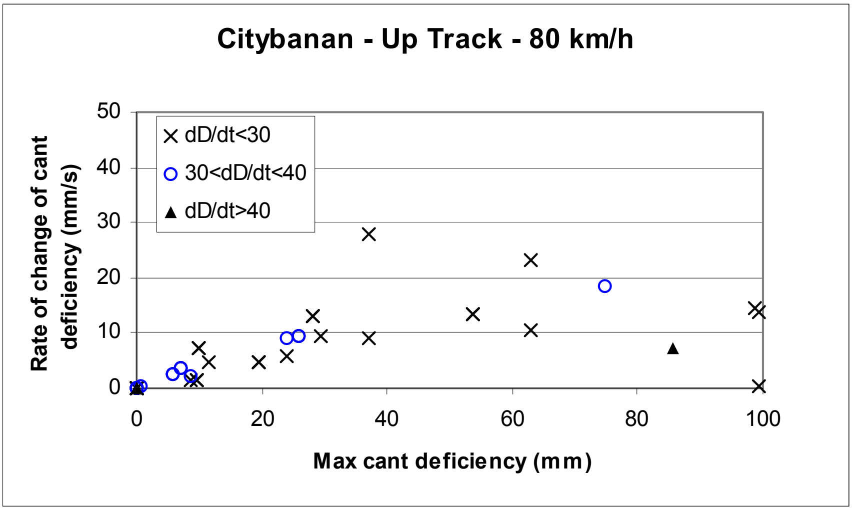

Figure 4: Cant deficiency, rate of change of cant deficiency and rate of change of cant (dD/dt) for the Up Track and a permissible speed of 80 km/h.

4 Examples of track layouts

4.1 General description of the horizontal alignment

From Tomteboda, the first 1.0 km long 3-track portion of the line will have an alignment permitting 95 km/h for Category A trains. However, trains may frequently stop on this part due to the interference with the capacity-constrained Mälar Line. Hence, the decision was taken to reduce the permissible speed to

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90 km/h and reduce the cant on a 426 m radius from 150 mm to 125 mm. After this first curve, the permissible speed increase to 100 km/h for trains of Category A. Between Stockholm City and Stockholm South, the permissible speed drops down to 80 km/h, due to a 303 m radius.

Values for cant deficiency, rate of change of cant deficiency and rate of change of cant for the transition curves in the Up Track are shown in Figure 3. Figure 4 shows the same values for the Up Track for trains that run at 80 km/h along the whole route.

It can be seen that the margins to the limits are considerably greater than the CEN recommendation [4] of 10%, and it must be emphasised that these margins have not increased the costs for the project (since the alignment fits into the allocated terrain corridor).

4.2 Track configuration in the northern end of Stockholm City

In the northern end of Stockholm City, the twin-track railway will split up into four platform tracks and there will be a scissors crossover between the two middle tracks, see Figure 5. The turnouts for the quadrupling will be frequently used both in the through tracks and in the diverging tracks. In this case, it was natural to choose 1:18.5 turnouts (with an instantaneous change of cant deficiency of 63 mm and 98 mm for 80 km/h and 100 km/h, respectively).

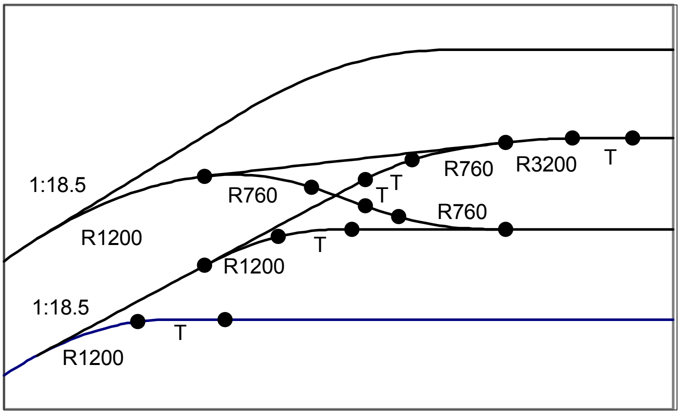

Figure 5: Track configuration in the northern end of Stockholm City (most important curves are indicated with radii).

The scissors crossover will only be used during traffic disruptions. Turnouts of type 1:14 (instantaneous change of cant deficiency of 99 mm at 80 km/h) were considered adequate. In order to minimise the length of the crossovers, the standard diamond crossing with the largest angle (1:4.44) was used and the curves behind the heel of the turnouts were extended to create the necessary angle. Transition curves were inserted wherever possible, even though the track standards allow the extended curves with radii 760 m to be connected to the straights through the diamond crossing without any intermediate transitions.

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The same apply to the through tracks: Unless a transition curve would cause an unfavourable geometry for an adjacent turnout, transition curves (indicated with *T* in Figure 5) will be provided wherever the radii change.

The whole configuration is minimised in length, in order to enable longitudinal positions for the platforms according to the architect's request.

4.3 Phase 2 re-configuration of Stockholm South

Stockholm South is an existing station on the Western Main Line, and is provided with four platform tracks (for all passing trains) and two pocket tracks for local freight traffic. All six tracks are placed below podium buildings.

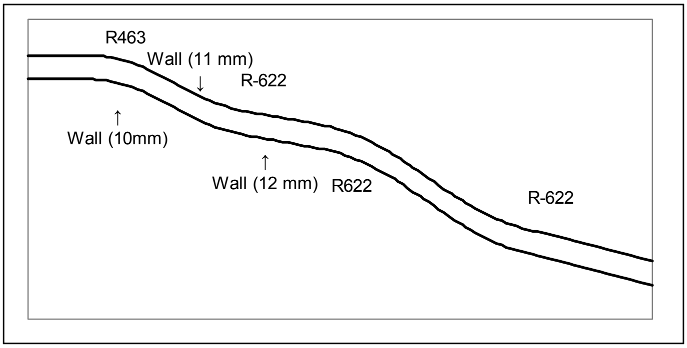

Figure 6: Future track layout for the Western Main Line at Stockholm South and margins to the structure gauge.

In the first phase, Citybanan will use two platform tracks for the commuter trains. The other platform will be closed, and its two tracks will be allocated for passenger trains and freight trains to/from Stockholm Central Station.

In the second phase, when capacity is to be raised from 24 to 30 trains per hour and direction, Citybanan must be provided with four platform tracks at Stockholm South. The two pocket tracks need to be changed to through tracks for Intercity and freight trains. The permissible speed on these tracks needs to be increased from 40 km/h to 80 km/h. Existing structures for road bridges and the podium buildings define a terrain corridor which is wide enough for the two through tracks, but the corridor was winding in an unfavourable way.

The structure engineer had to accept several re-definitions of the available terrain corridor before an alignment solution for 80 km/h could be found. The alignment design was based on a detailed survey and the margins for the structure gauge at certain locations are as small as 10 - 12 mm, see Figure 6.

5 Discussion and conclusions

A new railway, such as Citybanan, will be used during a long time. Track components, signalling systems, etc. may be upgraded at subsequent renewals. When a railway is built, the alignment will be more difficult to upgrade

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(especially for a railway in tunnel). Hence, future requirements should also be taken into account at early stages in the planning and design processes. Citybanan has been designed to accommodate future crossovers, future quadruplings of the stations and a future increase of permissible train speeds.

Alignment expertise was brought in at an early stage of the planning of Citybanan. It was found that one station alternative (Rosenlund) was not feasible, since turnouts for a future quadrupling could not be arranged. In the case of Stockholm South, it was originally uncertain whether or not the existing tracks for Intercity and freight trains could be re-aligned in order to give Citybanan four platform tracks. In this case, detailed design was necessary to ensure that the alternative was feasible.

The possibility to a future increase of permissible train speeds requires substantial margins to the limits for rate of change of cant and rate of change of cant deficiency. The 10% margin, proposed in the draft standard from CEN [4], is not considered adequate.

The detailed design of Citybanan will be carried through during 2004-2006. There may be changes in the alignment during the detailed design, but only if the borders of the alignment corridor change.

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