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Track-Structure Interaction in a New Concept of Station in Mechelen

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Abstract

Belgian Railways intends to renovate and to extend the existing station in Mechelen, Belgium; comprising of 10 tracks. The extension consists of creating space underneath the railway infrastructure over a length of 190m, instead of the actual individual gates. In using continuous rails, an integral part of 190m without rail expansion joints is impossible. Therefore four main parts of 3 times 20m length in longitudinal direction and two parts in lateral directions will be used. Therefore a 3 dimensional, instead of a 2 dimensional approach, is needed. In having a continuous track on this structure the requirements of the UIC774-3 must be kept in mind, such as a maximum rail stress due to the combination effect of temperature, braking, acceleration, rotation of the deck ends. The combination of all these effects is studied in a finite integral 3D-element model containing the geometry of the structure with rails and roof structure. This paper will investigate the influence of the column rigidity in function of the rail stresses and structure displacements in order to obtain the best working solution used for the final design of the new station at Mechelen.

Keywords: railway structure, ballast track, track-structure interaction, UIC774-3, station.

1 Introduction

In the city of Mechelen, Belgium the Belgian Railways has requested a new train station. The current station has 10 ballasted tracks placed directly on the ground. There is also a passenger tunnel underneath the tracks with stairways to access the passenger platforms.

Figure 1 shows a photo at platform level of the station. The whole renewal of the station, bridges are part of a larger project of the Bypass in Mechelen were 2

supplementary tracks are added connecting Mechelen with the Airport of Brussels [3].

Figure 1: Existing station of Mechelen – platform view

Figure 2: Existing passenger tunnel at station of Mechelen

The design requires that the current station remains in use during the construction. No more than 2 tracks may be obstructed during construction. Also it was important that the safety during construction is guaranteed, mainly concerning falling risks of big foundation machines near the tracks in service or damaging existing cables during excavation works. Those principles have an important influence on the design concept of the station.

2 New design

The new station exists of four fields of +/- 60m long. Each field has 4 column rows in track direction. In lateral direction the station has a high and a low part due to the existing situation. The station has 3 levels: a platform level, a ground level and a basement level. The columns of the higher platform contain 4 tracks and have a length of 814cm (from platform till ground level). The lower platform part has columns of 500cm high and contains 6 tracks.

Figure 3: Cross section of the new station building

These columns are mixed column sections with a steel tube of 1219x25 S355 for the high columns and 914x16 S355 for the low columns. The tubes are filled with a C50/60-concrete. This also helps the structure for fire resistance. The columns from the ground level to the basement levels are bored piles of 190cm in diameter for the high part and 135cm for the low parts with a C50/60-concrete as well. Each field is totally independent of the next field in longitudinal direction and the lower and higher platform parts are also independently constructed. The whole station has a wave-shaped roof structure and is made of steel. The steel structure is connected to the concrete structure at 2 times 4 places and is constituted independently of the next roof structure.

Figure 4: Simplified visualisation of the low platform structure with 1 roof section

The concrete plate at platform level is 140cm thick and contains a steel structure inside to simplify the casting, to reduce the slab thickness and to avoid a posttensioning system on an integral structure. The concrete plate at ground floor level is 50cm thick and takes the live load of the crowd. The basement plate is 35cm thick and is placed directly on the ground. The whole structure is integrally connected in one field, which means that the rigidity of the columns and floors work together through moment resistant connections to restrict the loads on the rails and to reduce the displacements of the deck at train loading. The aim is to avoid rail

expansion joints at the structural expansion joints. To obtain this, the rigidity of the structure must be raised carefully in order not to exaggerate the stiffness of the supporting structure. Figure 5 shows a longitudinal view of the new concept of the station. In blue the existing passenger tunnel is drawn. This remains in use during construction.

Figure 5: Simplified visualisation of the low platform structure with 1 roof section

The columns per field have a 3 times 20m spacing. The distance at the structural expansion joints between two different fields is 230cm. The structural expansion joint is in all floor levels and in the roof structure as well at every 62,30m. At every structural expansion joint there is “double” bore pile system. The forces in that system are smaller than the middle columns due to the continuous beam effect of the different concrete floors and the roof structure. This is needed since those bore piles are too close to each other and give a group effect at foundation level. The pile resistance of the two piles together is less than the sum of the two piles separately. In part 3 the erection method is discussed which affects the design.

3 Erection method

Figure 6 shows the existing situation at the time the construction works start. The right side shows the finished (now under construction) bypass structure with roof. The maximal allowed disturbed tracks are 2 for the lower and 2 for the higher part. The platforms in use should be safe and easily accessible by the passengers. This is obtained by using the current tunnel as a protection shield during the erection works. The existing stairways remain in use.

Figure 6: Existing cross section of station

In phase 1 the tracks 1 and 2 of the low part and track 10 of the high part are closed. The execution is made by making a temporarily retaining wall between the tracks in use and the closed tracks. This retaining wall is made in steps of 1m to avoid damaging existing cables. The excavation is made till the ground level. Once this level is achieved a bore pile machine is placed in the pit. This machine makes the bore piles from the ground level till foundation level. The fall risk is limited because the machine is placed in an excavation instead of a landfill. This means that the machine is placed on stable ground which is close compounded due to the historical loads. That wouldn't be the case with a landfill. Another factor is when the machine falls it rotates around the bore pile at ground level and will hit the retaining wall. This limits the danger to the tracks in use. After completing the bore piles, the mixed steel-concrete columns are placed, the concrete floor at ground level and at platform level are made. Simultaneously the roof structure is erected.

Figure 7: Phase 1

The same procedure is used for the next phase with tracks 3, 4 and 8 and 9. The final stage is almost the same except that the tracks 5, 6 and 7 can be done without a retaining wall. In a last step the soil underneath the ground level is excavated till the basement level and the basement slab is concreted.

Figure 8: Final stage

4 Design

The design is made based on the hypothesis that no rail expansion joint can be used. This is to avoid maintenance problems which impacts the costs and train delays. Since the lengths of the different parts are 60m, the expansion length at the structural

expansion joints will be around 60m (two decks). This can be reduced by using an integral connected deck with stiff columns. The design of the rigidity of these columns is based on the UIC774-3 requirements which are as follows:

$$\sigma_{rail;traction} \leq 92MPa \quad \text{Equation (1)}$$

and

$$\sigma_{rail;compression} \geq -72MPa \quad \text{Equation (2)}$$

under the combined effect of

- braking/acceleration (20kN/m per track with a maximum of 6000kN for braking)
- temperature difference between track and structure of +/-20°C.
- creep, shrinkage effect correspond with a temperature load of -10°C (this is added in the temperature loads) [4]
- rotation of the deck at structural expansion joints due to train loads

and the displacement difference between two adjacent parts due to braking/acceleration at the structural expansion joints.

$$\Delta u_{x;struct.joint} \leq 5mm \quad \text{Equation (3)}$$

A first step is to build a 3D-finite element model in Scia Engineer 12.0.1049 of Nemetschek. This model contains the stiffness and geometry of the whole structure. The loads of the roof structure, temperature loading as an overall and temperature loading on the track, braking loads, LM72 train loads in different positions, ...

Figure 9: Finite element model in Scia Engineer

The structure is in a straight alignment (no sharp curves in the tracks). The requirements as given in equations (1) and (2) (see [4]) are valid for the rail stresses in ballasted track. The track-structure interaction for ballasted track is given in figure 10.

Figure 10: Interaction track-structure for ballasted track

A loaded track is used for braking loads since this is a short term loading. This gives a much higher elasticity compared to an unloaded track system. The deformation to achieve the plastic region is set at 2.5mm according to UIC774-3. The plastic limit is 60kN/m track for a loaded track and 20kN/m track for an unloaded track. The last function is used for the temperature load since this is a long term load effect. The interaction is made in the finite element model by modelling the tracks itself with the correct cross section as shown in figure 11.

Figure 11: Track section used in finite element model

Figure 12 gives a detail of the connection between the structure and the track. This is made by rigid bars which are connected to the track with a hinge and a translation function according to figure 11.

Figure 12: Finite element model detail of interaction

The calculation is made with a non-linear process which takes the above linear/plastic function into account. It is also important to model a large zone before

and after the structure zone to simulate the continuous track on the normal track bed. Figure 13 shows the normal forces due to the different effects of braking forces. The 'braking_1' and 'braking_2' are braking forces at the structural expansion joint between the abutment and the structure. The 'braking_3' and 'braking_4' are the braking forces with its maximum loading at the middle of the structure and 'braking_5' and 'braking_6' at the structural joint between the first and second field. The 'braking_max' and 'braking_min' give the envelope of all the previous braking values and is used in combination with the temperature effect.

Figure 13: Braking forces in rail and envelope (D=135cm)

The temperature and creep, shrinkage loads for the same structure give the below graph. The impact is smaller than the braking effect, but it remains an important force to take in to account for this structure. As shown the negative temperature load is larger than the positive load, since the creep-shrinkage load works only in one direction.

Figure 14: Temperature forces (+/-20K) and creep, shrinkage (-10K) in rail (D=135cm)

The effect of the deck rotation due to LM71-loading is given below in figure 15. This effect is very small – or negligible – compared to the influence of the temperature and braking loads. Those forces are 1.6% of the forces due to braking alone.

Figure 15: Influence of deck rotation due LM71 forces in rail (D=135cm)

The global effect is given in figure 16. The compression limit of -72MPa and traction limit of 92MPa are drawn as well.

Figure 16: Rail stress due to combined effects (D=135cm)

The red and dark blue lines are the rail stresses for the track at the high column part. The brown and light blue lines are the rail stresses for the low column part tracks. This means the stiffness isn't enough for the high part. The displacement difference due to braking gives a maximum value of 9.6mm for the high columns which exceeds also the maximal allowable limit of 5mm. This is shown in figure 17.

Figure 17: Displacement at pier top [mm] under brake loads

The low column part has a 4.8mm displacement ($< 5\text{mm}$) and a maximum rail stress of $-59\text{MPa} > -72\text{MPa}$. This is acceptable. When the exercise is done for other diameters an optimal bore pile diameter can be achieved in function of the rail stress and displacement limits. In order to obtain the most favorable diameter a study is made in function of different bore pile diameters. Figure 18 shows the column stiffness in function of the bore pile diameter.

Figure 18: Relation stiffness [m^4] and diameter [m]

Figure 19 shows the variation of the rail stress in function of the diameter (stiffness) of the columns and figure 20 for the displacement limit. It can be concluded that in this case the displacement limit is the determinant criteria for the design of the columns.

Figure 19: Influence of bore pile diameter on rail stresses [MPa]

The stress limit gives for the high column part a minimal diameter of the bore piles of 150cm (practical diameter) with a stress of $-65.3\text{MPa} > -72\text{MPa}$. When the displacement limit is considered a minimal practical bore pile diameter of 190cm is needed (value 4mm).

Figure 20: Influence of bore pile diameter on displacement [mm]

The proposed bore piles are for the low part 135cm and for the high part 190cm and the most determinant condition is the displacement criterion under braking loads for the new design of the Mechelen station.

5 Conclusion

A preliminary design of the Mechelen station is done based on the criteria of UIC774-3 code to avoid rail expansion joints for maintenance and cost reasons, based on safety regulations during construction and based on architectural requirements. Finally it is required to avoid big disturbance of the passenger traffic during execution. The proposed design takes the above demands into account and is determinant for the concept. Furthermore it is noted that the displacement criterion is the strictest rule for the current design.

References

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