Influence of building the m2 subway on the existing Bessières bridge

Aldo Bisetti, Jacques L'Eplattenier, Dominique Tendon, GVH group by GVH Tramelan SA, Rue de la Paix 30 2720 Tramelan – CH

1. GENERAL PRESENTATION OF THE PROJECT

The building of the m2 subway under the Bessières bridge is composed of several works.

On the Cathedral side of the bridge there is:
- an underground structure of small length to pass under the abutment of the bridge
- a small gallery under the countervault of the bridge
- an opening of large size in the masonry to cross the pile of the bridge

The new St-Martin bridge crosses the street 17 meters under the main arch of the Bessières bridge.

On the Caroline side of the bridge there is:
- an important opening to cross the pile of the bridge as on the other side
- a station divided in a first part in the open air (L=15m, under the counter vault) and a second part underground (L=20m excavated in the abutment of the bridge composed of molasse and backfill materials)

After the station, a 150 meter long tunnel is build under the Langallerie street, at limited depth, between the existing buildings and in bad quality soils.
2. MODELING AND COMPUTATION

The works situated on the Caroline side are those which mostly influence the Bessières bridge.
In order to quantify this influence, different analytical models were elaborated. We gave up very quickly the idea to modelise the whole bridge with a single model considering the size of the mesh.

We decided therefore to resort to several partial models:

- 1 model for the central steel arches
- 1 model for the pile made of masonry
- 1 model for the countervault made of freestones
- 1 model for the abutment in which the station is excavated

Coupling all the models was considered but finally abandoned for the following reasons:

- non univocal response in elasto-plasticity
- great quantity of springs and case combinations in the context of parametric analysis
- practical difficulty to establish the response of several models connected in series

We finally decide to analyze separately each model, to estimate the deformability of them and to impose the calculated deformations to the adjoining model.

3. MODELING OF THE ABUTMENT AND THE STATION

The construction of the station will remove the major part of the abutment and a part of the foundation rock also made of siltstone.

Elements of reinforcement had to be set in place previously to the excavation which is realized in divided sections with progressive introduction of the supporting works.

3.1 REINFORCEMENT AND REALIZATION STEPS

The reinforcement elements are:

- an umbrella vault over the opening made of steel profiles
- a series of horizontal piles to balance the horizontal component of the forces brought by the vault
- a vertical concrete wall against the abutment to balance the vertical component of the forces coming from the vault
The figures 1 to 3 give different views of the model.

The model is composed of:
- brick elements for the soil and the abutment made of stones
- shell elements for the lining and for the wall made of concrete
- beam elements for the umbrella vault and the piles

The excavation is subdivided in the following way:
- excavation of the foot galleries
- excavation of the crown
- excavation of the core and finally excavation of the floor

The lining is introduced after each excavation step.

3.2 MAIN ASSUMPTIONS
- in the cross section: excavation in several steps according to the execution method
- lengthways: excavation in one single step with activation of the lining for a chosen deconfining rate (pseudo 3D, $\lambda = 0.5$)
- horizontal piles fully connected to the soil
- axial stiffness of the umbrella vault neglected
- influence of the tunnel's excavation not taken into account
3.3 MAIN RESULTS

- vertical deformations:
  - 1.5 cm on ground level
  - 2.5 cm on keystone of the excavation

- horizontal deformations:
  - small, less than 5mm

- horizontal piles:
  - balance half of the horizontal forces coming from the vault

- wall of concrete:
  - balance all the vertical forces brought by the vault and the rest of the horizontal forces not balanced by the piles

- lining made of concrete and steel arches:
  - normal forces and bending moments balanced by a 35 cm thick shell made of concrete reinforced by steel bars (diameter 20mm / spacing 15cm)
4. MODELING OF THE COUNTER VAULT MADE OF STONE

The construction of the subway doesn't affect directly the counter vault of the bridge. Consequently no reinforcement of this element is necessary before excavation of the station and the pile.

An analytical model of the vault was all the same developed in order to quantify the influence of the displacement imposed to the vault.

The model is composed of:
- brick elements for the masonry and the soil
- contact elements for the joints between the freestones of the vault

The figures 8 to 11 give different views of the model.

4.1 MAIN ASSUMPTIONS

- one meter slice of a 3D-model (transverse traffic eccentricity not taken into account)
- plane strain deformation state
- modeling of all joints of the vault
- deformation of the boundary supports imposed to the structure

4.2 MAIN RESULTS

- vertical displacements:
  - practically identical for the keystone of the vault and the ground level
  - for an horizontal displacement of the supports equal to 1 cm, the settlement of ground level reaches about 2 cm
The two inner stages are realized under the cover of the umbrella vault. The vertical loads acting over the opening are deviated towards the lateral piles and the concrete frame just constructed.

The FE model is composed of:
- brick elements for rubble stones and backfill material
- beam elements for cables and bars of reinforcement
- shell elements for lining

The figure 12 to 14 give different views of the model

5.2 MAIN ASSUMPTIONS
- Loads from the principal steel arches imposed to the pile (eccentricity of the traffic is taken into account).
- Loads from the counter vault made of stones imposed to the pile
- Elements of reinforcement introduced with the real ratio of prestress
- Excavation in several steps with progressive introduction of the lining
- Different stiffnesses between rubble stones and backfill material. According to a parametric analysis, a stiffness ratio of 1.0 was finally chosen

5.3 MAIN RESULTS
- Setting in place prestressed cables produces a compression reserve which is essential
- Building an umbrella vault insures the stability of the materials situated over the opening
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5.3 MAIN RESULTS
- Setting in place prestressed cables produces a compression reserve which is essential
- Building an umbrella vault insures the stability of the materials situated over the opening
- The vertical deformation over the opening is less than 4mm
- The horizontal deformation of the pile is limited to 7mm at the upper level of the hole
- The rotation of the pile due to eccentric traffic is very small

5.4 ANALYTICAL MODEL

A simple model composed of traction and compression elements was used next to the FE sophisticated model. This basic model, based on balance conditions at yield, represents an interesting tool to evaluate the necessary reinforcement. The FE model remains however essential for quantifying the deformations.

6. MODELING OF THE MAIN VAULT MADE OF 5 METALLIC ARCHES

The construction of the subway doesn’t affect directly the central vault. Similarly as for the counter vault no reinforcement of the steel arches is planned. However the influence of an horizontal displacement of the vault’s birth on the metallic structure has to be analyzed with a FE model.

Facilities concerning the introduction of the different loads and concerning the treatment of the results have led to use a specific program for structures. Minor adaptations of Zsoil program would allow this one to treat this kind of problems too.

The figures 15 and 16 give different views of the model.
6.1 LOADS

- permanent (steady state) loads
- traffic
- wind and temperature

The loads are increased by specific factors and combined together. The most unfavorable load combination leads to a stress state which represent the reference for the analysis. Imposing a symmetric displacement of the supports represents a supplementary load which induces additional stress. The displacements of the supports present a uniform shape and a differential one.

6.2 FINAL RESULTS

The additional stresses induced by an horizontal displacement of the supports are moderate and acceptable for the metallic structures.

7. CONCLUSION

The modeling of the whole bridge with a single FE model revealed to be almost impossible and in any case not really interesting. On the other hand it was worthwhile to restrain the size of the meshes in order to analyze the influence of several parameters.

In this particular case, the splitting of the global model into 4 partials models allowed us to establish that all the structures were able to stand an horizontal support displacement of 1 cm without any problem for the structure. At the same time less sophisticated models, exclusively based on a state of balance at collapse, appeared sufficient to design the reinforcement elements.

The simultaneous use of the 2 types of models revealed interesting for saving computation time as well as for developing a diversified approach of the problem.