

# **Recent Austrian Experiences in Design, Construction and Monitoring of Integral Bridges**

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## **ABSTRACT**

Integral bridges are in most of the cases structural frame bridges without bearings and joints which are characterized by a high degree of static indetermination. In spite of the fact that this type of a structure has become in recent years more and more interesting to bridge owners, who count on significant savings in terms of structure maintenance as a result of the absence of the highly vulnerable bridge infrastructure (bearings and expansion joints), the acceptance of integral structures among designers and building-owners when it comes to longer structures continues to be low. The reasons for this are the numerous uncertainties in design which can be attributed to the evolution in time of the strength of materials, to the creep and shrinkage processes in the concrete, to the interaction between soil and structure with temperature changes, as well as to appropriate modeling possibilities for this interaction. This applies especially to bridge lengths exceeding 70 m where you can find today, mostly in the area of the abutments, expansion joints and bearings.

In the framework of several projects in Austria attempts have been made in recent years to gradually also approach longer integral bridges and to study them in detail within research projects or monitoring systems in order to determine their actual structural behavior. A mandatory guideline was prepared over some years within a national task force meant to regulate the calculation and execution of integral structures. The present article illustrates the experiences which have been made so far in Austria with this type of bridge by providing some concrete examples.

## **INTRODUCTION**

With jointless bridges, the supra-structure and abutment are connected monolithically with each other and thus go fully without bearings and expansion joints. The entire structure is embedded in the foundation ground and backfill. The monolithic connection of the supra-structure and abutment allows for very aesthetical solutions which are convincing also from the point of view of statics – for example by the use of the frame structure. The frame opens system reserves by shifting internal force variables and leads to a robust structural behaviour.

The terms “jointless”, “monolithic”, and “integral” (building a whole) are used in the same way in the general linguistic usage. The supra-structure of an integral bridge construction runs jointlessly through the entire bridge length and is not interrupted, either from the columns or from the abutment via joints and bearings – hence it is monolithically connected. Deformations like shifting and rotation, resulted especially from temperature, are generally directly transmitted into the foundation ground and backfill in which the bridge is embedded.

Important differences in terms of structural behaviour between an integral and a conventional bridge emerge from the mainly high static indeterminacy of integral constructions, as well as from the interaction between soil and structure which is decisive for the calculation and structure behaviour.

Semi-integral bridges are an intermediate bridge type (conventional bridge and integral bridge). This construction type is based on a monolithical connection between inner columns with their foundation and the load bearing structure. However, in the abutment area there are bearings and possibly even expansion joints.

## **DEFINITIONS IN AUSTRIA**

In this context, one should be aware of the fact that at international level there are some differences of opinion in terms of the bearing system and the type denominations resulting from it. In the D-A-CH (Germany, Austria, Switzerland) region, in particular, there are a series of terminological variations in usage. In Austria the following definitions have been agreed on:

- Integral bridges are bridges with no bearings and expansion joints in the supra-structure, as well as between supra-structure and abutments;
- Jointless semi-integral bridges: load bearing structures where the inner columns are connected monolithically with the bearing structure and the foundation. The relative movements between the load bearing structure and abutments are performed through bearings. The transition from the supra-structure to the roadway is done without any joint.
- Semi-integral bridges with no bearings: load bearing structures where the use of bearings in the supra-structure, as well as between the supra-structure and sub-construction is completely eliminated. The transition from the supra-structure to the roadway is done with the help of a joint (expansion joint).
- Bridges with bearings: conventional load bearing structures

## **MAIN CHARACTERISTICS OF INTEGRAL BRIDGES**

The following characteristics have to be mentioned when it comes to integral bridges:

- As a result of the restrained deformations, conditioned by thermal stress or irregular settlement of supports, forces emerge which influence the behaviour of the whole load bearing structure.
- With pre-tensioned load bearing structures one should be aware of the fact that part of the pretensioning force is not active in the supra-structure, but flows via the sub-constructions directly into the foundation ground.
- The extent of the resulting imposed stresses depends significantly on the construction geometry, the stiffness ratio between supra-structure and sub-construction, as well as on the stiffness of the foundation ground.
- If the estimation of the foundation ground stiffness is too low, the restraint actions due to temperature and pre-tension are sub estimated.
- With integral bridges a separate study of the upper and lower limit of the soil parameters is necessary for the calculation of the restraint actions. This results on the one hand in a certain design uncertainty, as well as higher complexity of the bearing structure design and a stronger interaction between the bridge designer and the geologist.
- Despite the restraint, one can usually expect quite similar changes in length due to changes in temperatures as with conventional bridges, given that the assumption is that the abutment, as well as its foundation ground, cannot be shaped stiff enough.
- The displacements are not compensated at the expansion joint between the supra-structure and the abutment; instead they are passed over via the abutment into the backfilling.
- Depending on the respective change in temperature, the backfilling undergoes both negative and positive wall movements (static pressure, active and passive earth pressure) whose extremely values are subject to a year cycle.
- The earth pressure existing right after construction (compression earth pressure) is released with the first positive wall movements (to the inside) in the active earth pressure.
- With negative wall movements (to the outside), however, parts of the passive earth pressure are activated, especially in the upper earth layers.
- The cyclical repetition of the movement as a result of changes in temperature causes a progressive compression of the backfilling. The consequences are settlement processes in the backfilling area and hence an increase of the earth pressure. This makes the use of drag plates necessary.
- The transition from condition I to condition II has to be considered; the internal force variables emerging from the restraint are thus considerably reduced.

Bridges with no expansion joints and bearings bring a series of advantages, but also disadvantages as compared to conventional bridges. Expansion joints and bearings are always potential weak spots of a construction. Nowadays bridges are calculated for a life cycle of up to 100 years. The elimination of joints – which depending on the exposure to traffic and weather can have a significantly shorter life cycle – improves the durability and maintenance costs of a bridge. In many cases there is also an increase of the bearing capacity of the structure. This is important exactly in what concerns redundancy against extraordinary actions. The advantages can be summed up as follows:

### **In the design phase**

- Compensation of uplift forces with unfavourable span through self-weight of sub-construction and foundation, as well as skin friction of the piers. This makes shorter end spans possible whereas in case of 3-span constructions you can achieve larger middle spans.
- The restraint in the abutments allows the construction of slim and aesthetical supra-structures.
- Support of the horizontal loads emerging from the earth pressure through the load bearing structure and possibility for direct discharge of the horizontal loads in the ground earth.
- By avoiding the use of bearings you can avoid stress concentration and the resulting splitting forces. The whole force flow within the construction becomes more continuous.
- High cutting force shifting is possible in the ultimate limit state (ULS).
- Reduction of the risk of irregular settlement and misalignment of the piers.

### **In the process of construction**

- Simpler and faster construction progress as a result of the elimination of bearings and expansion joints with the corresponding low tolerances and sequence.
- Easier design and construction of the abutment

### **For users and neighbours**

- Higher driving comfort by avoiding expansion joints, as well as especially in populated areas lower noise emissions resulting from vehicle crossing.
- Safe vehicle crossing for the single-lane traffic.

### **Maintenance**

- Reduced maintenance costs as a result of the elimination of bearings and expansion joints.
- Increased durability and lower maintenance need for the construction parts under the carriageway by avoiding the direct access of de-icing agents.
- Increased ductile behaviour of the load bearing structure by activation of system reserves.
- Longer inspection intervals as compared to conventional construction methods according with the Austrian Guideline for the control, monitoring and inspection of constructions.

As compared to conventional bridges, the following additional aspects, however, should be taken into consideration upon design, calculation and execution:

- Restraints emerging from changes in length (temperature, shrinkage, pre-tensioning, creep) and settlement differences.
- Dependence of the imposed stress on the construction geometry, the rigidity between supra-structure and sub-construction, as well as the rigidity of the foundation ground.
- Reduction of the normal force ratio of a pre-tensioning force in the supra-structure by discharge into the sub-construction and foundation ground.

- Integral bridges undergo as a rule, despite the restrained free deformations, considerable changes in length as a result of changes in temperature. They should be taken into consideration in all project stages.

## **LOAD BEARING CHARACTERISTICS AND CALCULATION OF INTEGRAL BRIDGES**

Integral bridges are subject to the same actions as conventional bridges, the restraint actions for the construction, resulted due to marginal conditions, are, however, higher.

Within the traditional bridge construction methods, especially as concerns pre-tensioned bridges, the requirement for a potentially restraint-free positioning of the supra-structure in longitudinal direction for horizontal forces is an essential design principle.

The same as with conventional bridges, with integral bridges the foundation should be made so as to experience as little settlement as possible, namely as a rigid foundation. In order to be able to control the internal force variables within the construction, a certain elasticity of the foundation, backfilling and sub-structures is necessary. Based on this aspect an optimization task has to be performed during design.

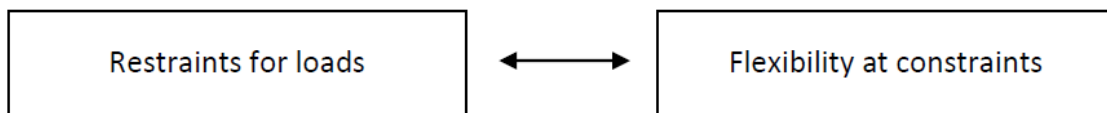


Figure 1. Optimization problem in calculation of integral bridges (Schlaich et.al 1996)

### **Supra-structure**

The construction geometry, as well as the rigidity of the abutments has a dominant influence on the imposed stresses. Through the alignment of the abutments of integral bridges as much vertically to the main direction of the movement of the structure ends as possible you can avoid rotation movements in the horizontal plan, the slipping of the entire structure and an increased earth pressure stress in the blunt frame corners.

In case of skew abutment alignment, one should pay attention – especially with small frame constructions with ample inclination – to the emerging translatory and rotatory deformations.

Curved bridges can partially absorb the changes in length through radial shifts. The resulting radial shifts (vertical and horizontal) and rotations have to be proven in terms of serviceability criteria. Important are in this respect mainly the rigidity and geometry of the columns, as well as the rigidity of the supra-structure. Starting 2014 there is the requirement to perform measurements at such curved structures and compare them with the assumptions of the static calculation. In Switzerland, for example, long term studies have been performed at a bridge with an opening angle of about 90° (dsp ingenieure, 2012).

### **Transition load bearing structure – free field**

The changes in length resulting with integral bridges between the dam structure and the load bearing structure after construction of the top layer have to be absorbed through appropriate constructions in the transition area.

In order to avoid unacceptable high deformations in the backfilling area, constructive measures have to be taken in the transitional area, in accordance with the bridge use and route. These measures can include the following:

- Measures of lower complexity: for example separating cuts in the road surface behind the load bearing structure, etc.
- Measures of higher complexity: drag plates of the most different type, special requirements in terms of backfilling, use of concrete wedges, concrete backfilling, etc.

Drag plates offer the following advantages:

- Rigid transition between the load bearing structure and the surrounding ground and compensation of possible settlement of the backfilling
- Shifting of the concentration of movement in an area behind the load bearing structure at the end of the drag plate which is less critical in terms of maintenance.
- Discharge of deformations in deeper layers and distribution of expansion in the carriageway surface on a longer distance

No such measures are necessary for bridges with small structure lengths and segments with continuous carriageway surface and conventional backfilling. The following reference values are applicable:

- Total length  $\leq 40$  m: no measures (continuous carriageway surface)
- Total length  $> 40$  m: with measures starting with separating cuts in the road surface over drag plates and longitudinal flexible drag plates, etc.).

## **Abutments**

The design of integral structures requires the consideration of the interaction between the ground and the construction. In this context one should consider especially the elasticity of the foundation, the elasticity of the backfilling material, the earth pressure activated by the abutment wall movement, the rigidity of the abutments and their foundation, as well as the effects resulting from the constructive execution in the abutment area.

In terms of the construction of the abutment, as well as in terms of the interaction behaviour there are the following possibilities for the realization of the abutments:

**Flexible abutment:** the aim of a flexible abutment construction is the reduction of restraints within the supra-structure through an elastic sub-construction. The absorption of the emerging relative shifts to the adjacent embankment, as well as the earth pressure activated thereof have to be proven and taken into consideration from a constructive point of view (for example through elastic layers between the abutment and embankment, etc.). An example for a flexible construction based on extremely complex measures is the alignment of a soft inlay behind the abutment in combination with a self-supporting embankment (see the example Seitenhafenbrücke).

**Conventional abutments:** the aim of the conventional abutment construction is to avoid concentration of movement in the difficult to prove special constructions (reinforced soil, permanently elastic intermediate layers, inclination of the front wall, etc.) of the flexible abutment.

**Rigid abutment (special case):** The aim of a rigid abutment construction is the considerable reduction of the emerging relative shifts at the abutments. This is usually only possible with rigid foundation on rigid rock. The assumption that a rigid abutment can be achieved through a as much as possible massive construction of the abutment like in Figure 6 has proven to be, following long term measurements, not correct (see Oberwarther Bridge). In spite of the

box-shaped abutment with 8 transversely positioned bored piles, the measurements indicated almost the same shifts of the load bearing structure as with conventional construction.

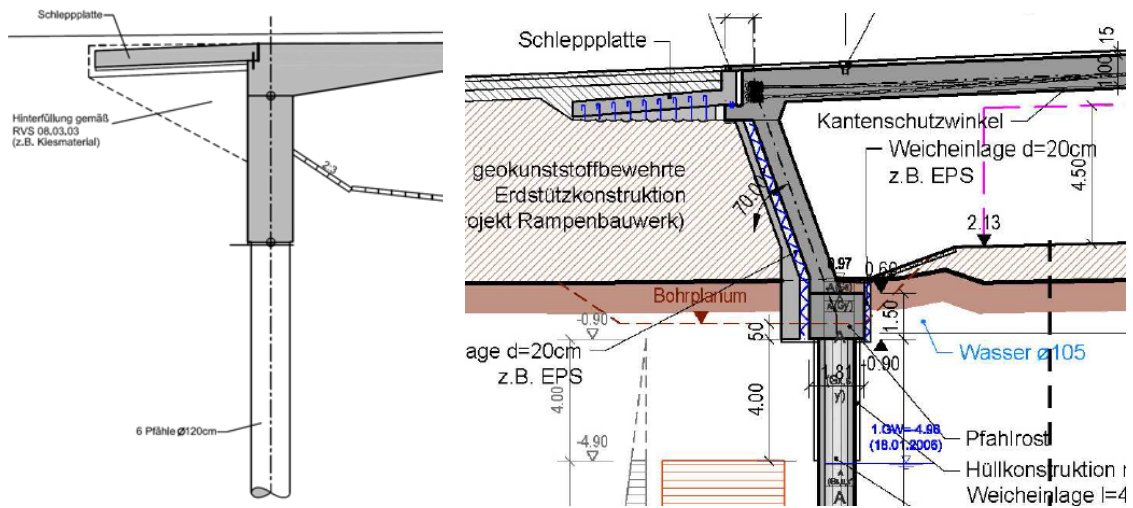


Figure 2. Flexible abutment construction with deep foundation (left) and soft inlay (right)

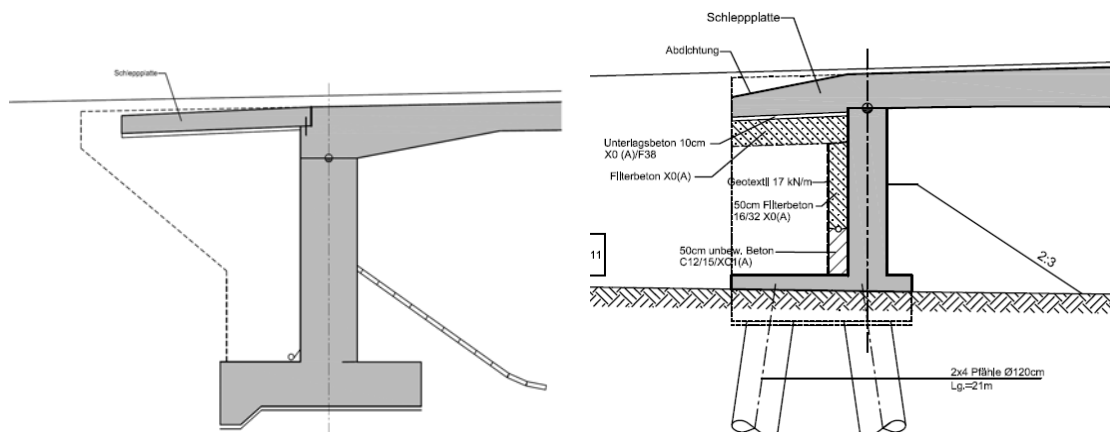


Figure 3. Conventional construction with flat foundation (left) and box-shaped abutment with deep foundation (right)

The influence of wing walls on the rigidity of the abutment has to be taken into consideration whereas the rigidity of the abutment can vary due to the wing (for example hanging wings or box-shaped construction).

### Earth pressure approaches with integral bridges

In terms of earth pressure actions on the abutments of integral bridges one should consider the following limit cases:

- Reduced earth pressure coefficients as a result of the shortening of the load bearing structure (lower limit: active earth pressure with conventional backfilling and 0 with self-supporting backfilling)

- Increased earth pressure coefficients as a result of the extension of the load bearing structure

In case of symmetrical load bearing structures, the movement point of rest can be estimated in the middle of the load bearing structure. In case of asymmetrical load bearing a structure, the movement point of rest has to be determined taking into consideration the rigidity of the load bearing structure, the geometry, the foundation and the backfilling. The deformations of the abutments and the estimated earth pressures require a separate assessment together with the geologist. The cooperation between the designer of the structure and the geologist is with integral bridges of utmost importance. This is why in Austria it has been decided that in the framework of the structural design, with structure lengths  $> 50$  m, the geologist has to determine the maximum activated earth pressure and the working depth.

If no special measures are provided for in the backfilling area for structure lengths  $< 50$  m, higher earth pressures than earth pressure at rest are possible. This is why one should estimate an upper limit value of  $1.5 \times$  earth pressure at rest above the foundation lower edge.

The following measures and their combination are an example for how you can reduce the earth pressure projection:

- Permanently elastic (compressable) layers
- Self-supporting backfilling (for example: woven geotextile, lime and cement stabilisation and lean concrete)
- Sheets of drift between hanging wings and backfilling (for example PE-foil with geomembrane) in combination with a drag plate

## Columns

The rigidity of the columns influence the internal force variables of the load bearing structure and have thus to be taken into consideration upon modeling and calculation. The factors which influence the rigidity of the columns are the column geometry (height, section), the foundation of the columns, the characteristics of the concrete, the normal force stress, the long term effects (creep, shrinkage, relaxation), as well as crack formation.

The increase of the spans by reducing the number of columns can lead to a reduction of the deformation capacity of the bridge on the longitudinal axis and as a result to an increase of the restraint actions in the supra-structure. The material, section form, the knod construction at the head point, the alignment of concrete haunches and the column lengths (or maybe pile lengths) are the most important design parameters.

For the choice of the section form it is recommended to have a regular distribution of stress (in the state II uniform distribution of the admissible crack width) along the pin of the framework in order to ensure a uniform deformation of the columns. Haunched pile end sections allow alternatively a favourable deformation able behaviour. The widening of the pile section at the connection to the supra-structure generally leads to a shifting of the plastic hinge towards the middle of the pile, which creates higher rotation ability.

The reduction of the restraint actions within the supra-structure maintaining at the same time the structural safety of the columns can be achieved through the construction of a double pile structure.

With curved bridges in the horizontal plan the choice of section of the columns in cross section, given the radial pile deformations, has a considerable influence on the imposed stresses in the longitudinal plan of the supra-structure.



## **Foundations**

The rigidity can be controlled depending on the way the foundation is executed. A horizontal softer system with a deep foundation can be achieved by the alignment of only one row of piles. The upper area of the piles can also be realized softer by enveloping them with a soft inlay or jacket pipe (see example Seitenhafenbrücke). With the help of support structures with potentially inclined piles (see example Oberwarter Brücke) the rigidity of the foundation can be increased within certain limits.

For the activation of a high deformation capacity and for avoiding high restraint actions, it is preferable in case of deep foundations and flexible abutments to have a one-row instead of a multi-row alignment of the piles. The following principles should be taken into consideration upon construction of pile foundations:

- The piles should be considered within the structural system with realistic rigidities.
- A single row of piles is suited for a flexible abutment and columns.
- For a less flexible abutment and columns grouped piles are suited, potentially as inclined piles.
- The calculations should be performed based on marginal values.
- If a reduction of the rigidity in the upper area of a pile is the target, one can have either soft inlays or decongestion with the help of an excavator (economic alternative depending on the given soil).
- The skin friction of the piles can only be assumed in safe areas (cyclic stress in the upper area of the piles).
- Elastic layers in the upper area of the piles increase the elasticity of the foundation.

When constructing deep foundations one should consider the following principles:

- Gaping joints in the underground have to be avoided (uplift forces).
- More rigid abutments can be achieved through a box-shaped construction.
- Soft abutments can be achieved through a disc-shaped construction or rather through an increased height of the abutments.

## **INDICATIONS FOR THE CONSTRUCTION**

Given that with integral bridges the imposed stresses have a considerable influence on the design, one should take into consideration some aspects concerning their construction.

By increasing resistance of the piles to deformation, the construction sequence for the reduction of restraint actions gains more importance. By increasing thickness of the structural elements, however, the influence decreases. One should also take into consideration the influence of the construction sequence on possible measures for the reduction of earth pressure. Through a targeted control of the construction date, time dependent deformations and the restraint actions resulting from them can be reduced.

Concreting areas: in order to reduce the restraint actions resulting from shrinkage, the construction of the supra-structure can be performed at the same time, starting from the two abutments which serve as fixed points. In this way, parts of the shrinkage deformation can already be anticipated before closure of the superstructure. This construction sequence is suitable especially for long construction periods.

Alternatively, the construction sequence for the reduction of restraint forces can take place starting from the piles, following the cantilever method, or on falsework. The joint connection is performed only after completion of all piles with their supra-structure elements.

Best time for pouring the concrete: low temperatures at the moment of closing the gaps are convenient. Integral bridges should be cast if possible at cold temperatures.

Types of concrete: during the construction it should be ensured that the concrete quality provided for in the design phase for the bearing structure is used. Post-limit stiffness should be avoided through the resulting restraint actions and the reinforcement meant to restrict crack width. As a result of damages which occurred in Austria in the past due to the use of concrete with higher stiffness, this topic is given an increased attention during the construction phase.

## **SIMPLE FRAME CONSTRUCTIONS**

This type of construction is realized in Austria as single or multiple span structures up to lengths of about 65 m mainly in reinforced concrete, whereas also integral composite structure bridges gain more and more importance given the faster construction time. A special example for the large-scale application of this type of a bridge can be provided based on a large project implemented by the company Schimetta Consult as a leader.

North of Vienna, a highway section 51 km long with more than 100 civil engineering structure works (among them 78 bridges) was built in the framework of a large PPP project (Private Public Partnership) in only 3 years including the design and construction phases, starting with the detailed design. The dimensions of the project – especially its complexity and short period of construction – are unique for Austria. Given that the life cycle costs and especially the maintenance costs were also a decisive issue in terms of the financing of the project, 80% of all the bridges were built as integral structures. The rest of the bridges were built as semi-integral constructions. The maximum inner widths with one-span frames cast in reinforced concrete were up to 34,5 m.

Given the large number of load bearing structures – in order to be able to fulfill the requirements concerning the constructions in terms of durability – a template design was elaborated which, depending on the length of the load bearing structure and on the underground, contained certain specifications for the construction of the abutment, foundation and especially of the transition area between open space and structure.

In most of the cases they tried and try not to realize any special measures concerning the carriageway, which means that the carriageway surface in each and every section is applied on the structure without joints. The use of a deeply embedded drag plate like the one in Figure 10 proved to be very favourable in this context, given that the changes in length can be distributed in deeper ground layers and thus on a larger impact length.

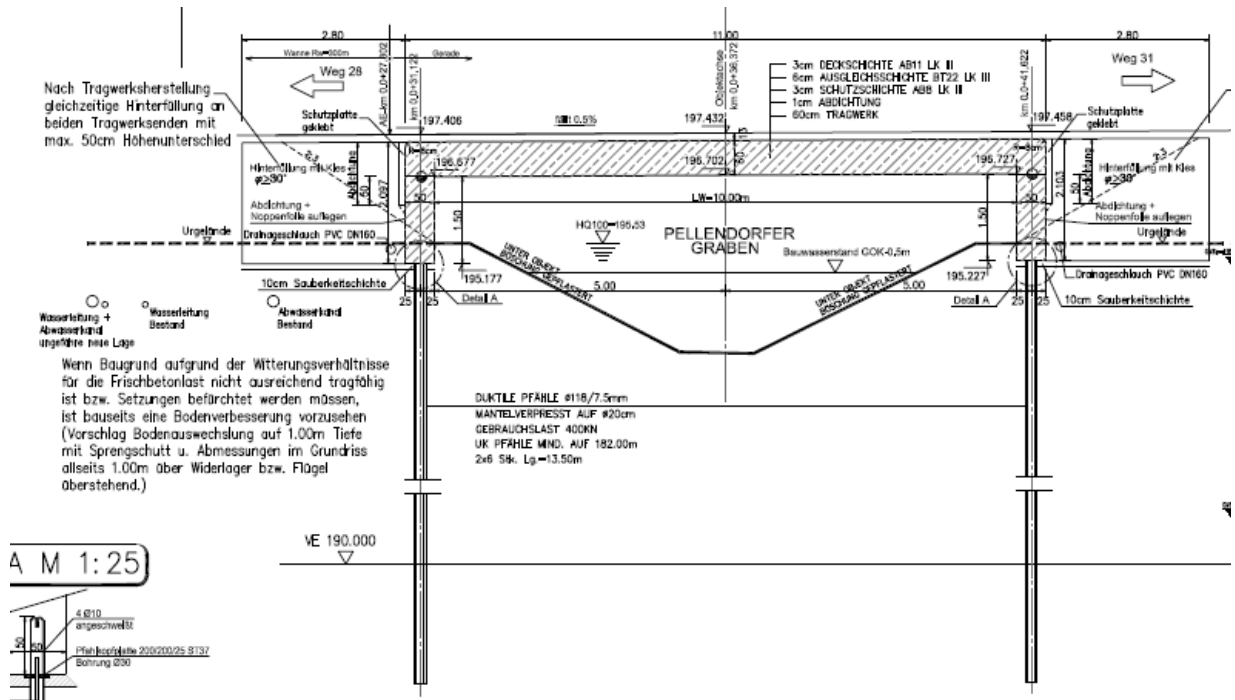


Figure 4. Integral bridge with ductile pile foundation

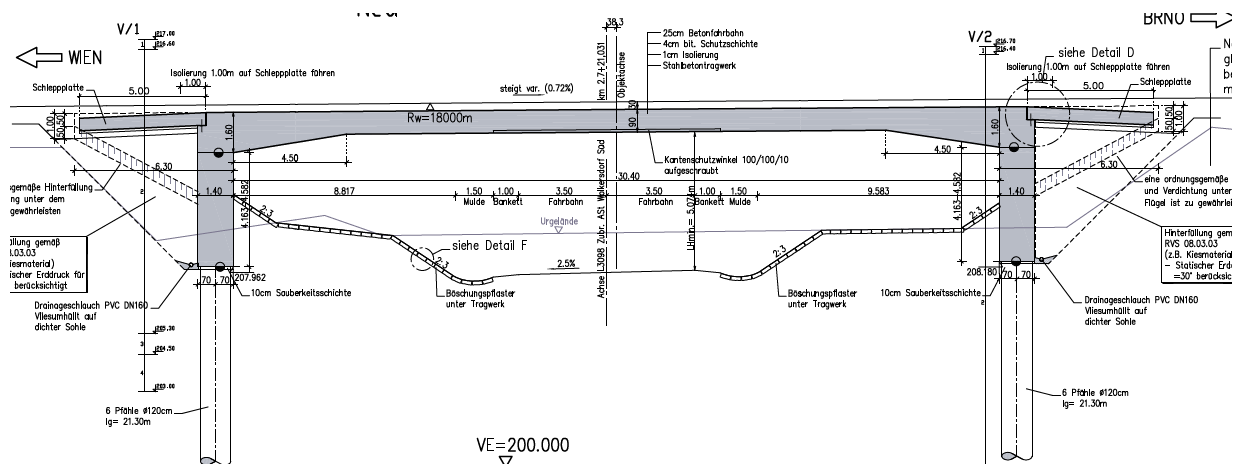


Figure 5. Reinforced concrete frame with deep foundation and inner width of 30,4 m

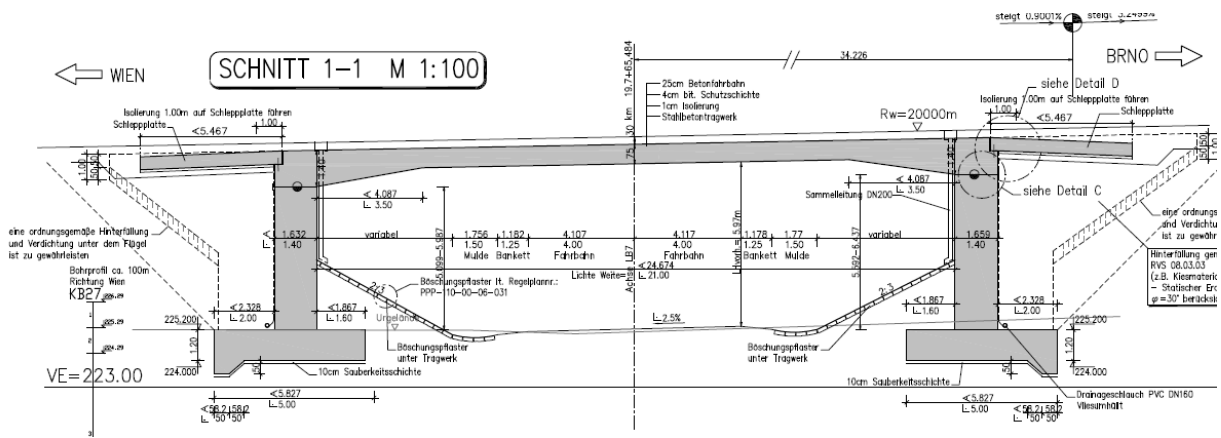


Figure 6. Reinforced concrete frame with flat foundation and inner width of 24,7 m

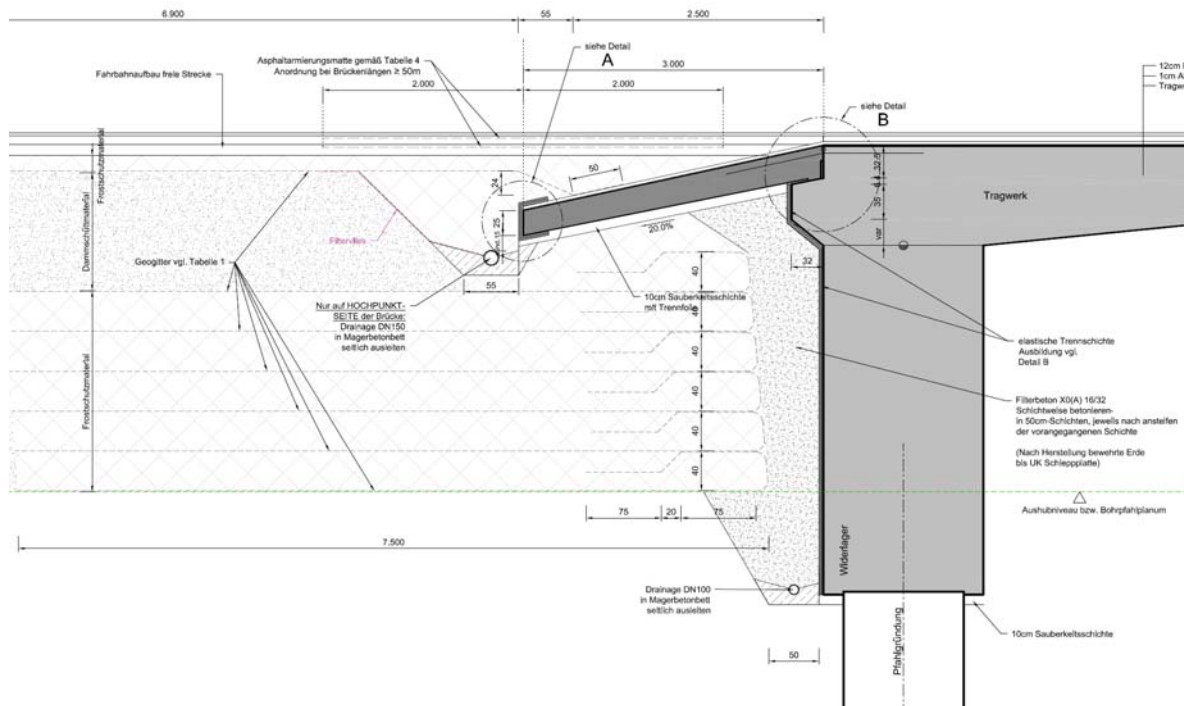


Figure 7. Abutment with deeply embedded drag plate

One further reduction of the maintenance costs was achieved by the realization of directly drivable, integral frame bridges. In this sense the construction of a separate sealing layer and carriageway surface was renounced. In order to fulfill the requirements in terms of the durability of the structure, the upper 40 cm of the structure concrete were cast in high-performance concrete quality C34/45/HL-B/XF4(A)/XM2 and wet processed with the conventional concrete.

The load bearing structure has as one-span frame an inner width of 32,0 m and only 0,80 m construction height centre span. At the frame corner the structure is widened at 1,50 m construction height. The maximum slenderness in the middle of the bridge is thus 40.

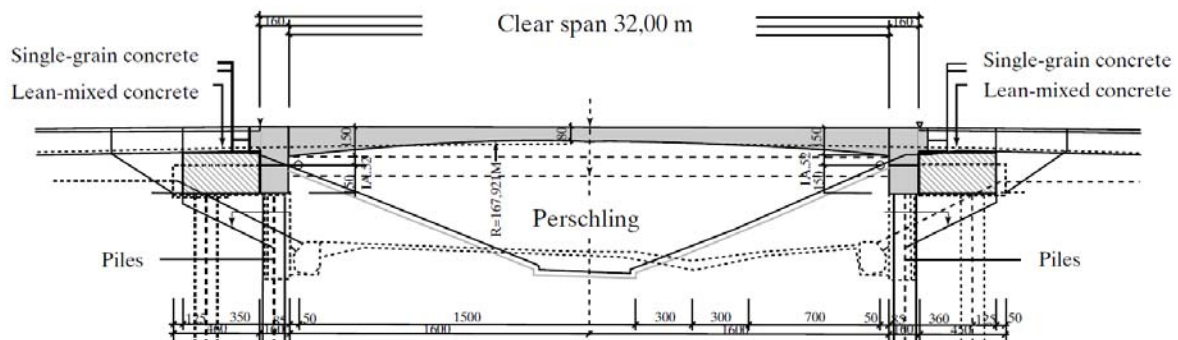


Figure 8. Longitudinal section through the direct drivable concrete bridge (Geier et.al 2010)

For the calculation, the restriction in terms of crack width as a result of renouncing the sealing and carriageway surface was of major importance. In terms of the high-performance concrete there was a restriction of the crack width to 0,2 mm. For all other areas, standard crack width of 0,3 mm were estimated.

Major advantages of the construction are the lower production costs, the reduced construction height, shorter construction time, as well as reduced maintenance costs. Also in terms of the execution of the construction works, the elimination of the sealing and bitumen carriageway surface brings considerable advantages due to independence from the weather conditions.

## STEYRTALBRÜCKE

Between Linz and Selzthal along the Phyrnbahn-railway a viaduct above the retaining lake Steyr close to St. Pankraz was renewed in 2013 and 2014. One major design criterion of the ÖBB Infrastruktur AG as a building owner was the realization of an optimised bridge construction in terms of Life-Cycle-Cost, which, among other things also despite the considerable length of the bridge, should go without maintenance intensive rail expansion joints. Starting from this concept, the Life-Cycle-Costs (LCC) were considered a decisive criterion and were opposed to the concept of the reinforced concrete arched bridge – which was finally designed and is presented further below.

One relevant advantage for the reinforced concrete arched bridge resulted from the idea of the possibility to renounce the use of rail expansion joints. In this context the issue of the interaction between the rail and the load bearing structure had to be looked into in detail in an early design phase already. Within a close, iterative decision-making process with the participation of the building owner (ÖBB Infrastruktur AG), the competent operator (the same ÖBB Infrastruktur AG) and Designer (Schimetta Consult) constructive marginal conditions, the calculation basis and the limit values to be met were established.

Starting from the normative requirements, as well as from the creative freedom which the applicable regulations allow for, the design underwent special methods for the determination of the rail tension emerging from the interaction. The results of the calculation concerning the

interaction between the rail and the load bearing structure finally allowed for the elimination of the rail expansion joints despite a total length of 182 m and very narrow rail radiuses.

Except the reduction of the number of distortion bearings through the monolithical construction method at the piles and at the arch crown, it was exactly this semi-integral construction which rendered the elimination of the rail expansion joints possible. The high horizontal stiffness of the arch could be used for the absorption of the horizontal forces in such a way as to be able to keep the additional rail tensions resulting from the interaction between the rail and the load bearing structure low enough.

The new bridge has an arch opening of about 98 m. The arch rise is  $f \approx \frac{1}{4}$ . The clear height at the arch crown is 26m over the average water level. The arch is connected on the Linz side with a two-span foreshore bridge and on the Selzthaler side with a three-span bridge. The piles are built as double piles with a cross section of 1m x 1m each. The highest effective slenderness of the piles is  $\approx 80$ . The 2 web T-beam is a continuous beam with nine spans. The regular span width is 17,5m. The connection to the piles and the arch is monolithical.

At the abutments the supra-structure is set on one elastomeric bearing which can be swayed longitudinally and one elastomeric bearing which can be moved to all directions. The horizontal forces resulting within the structure in the bridge longitudinal direction are absorbed by the arch. Thus the total span is 180,5 m. The width of the slightly reinforced T-beam is without cantilever plate 2,20m.



Figure 9. View on the Steyrtalbrücke currently under construction

At the beginning of the design the idea emerged to replace the existing steel frame bridge by a similar construction. The preliminary considerations envisaged a modern composite frame bridge made of steel and concrete with reinforced concrete deck at the top. This load bearing structure should have been designed as continuous three-span beam. At the end of the day, the reinforced concrete arch bridge proved to be from the perspective of the LCC by approximately one fourth cheaper than the composite frame bridge of steel and concrete. Except for the cheaper production costs, it is also the maintenance and servicing, as well as the elimination of rail expansion joints which account for a considerable economy.

## **OBERWARTER BRÜCKE**

The bridge 14005 is a 4-span reinforced concrete construction with a total length of 90 m built as an integral structure. Based on the minimum clearance outline imposed, a 4-span system was chosen, whereas there was so much space between the traffic routes that the inclination of the support beams was the best choice not only for aesthetical reasons, but also in order to

ensure the reduction of the wing-spans. For the reduction of the load concentration on certain columns and in order to achieve as much as possible a soft column, round, tensioned columns were designed at the bottom and at the top which are based on single-row piles. The load bearing structure as such was built as a massive construction of reinforced concrete. The thickness of the load bearing structure in the mid-span is 0.90 m and 1.40 m due to the concrete haunches in the area of the abutments and of the columns.



Figure 10. View on the Oberwarter Brücke

The particularity of the bridge construction refers, however, to the construction of the abutment, as well as of the transition area to the open space. With integral bridges of this length it had been preferred in recent years to use more and more frequently costly, flexible abutments with soft inlay or similar materials. Given that in this case the movements were to be concentrated not immediate behind the statically high exposed frame corner at not testable place, an alternative solution was developed together with the building owner, the Department for Bridge Construction of the Federal State Burgenland.

The objective within the design was to provide for as much as possible a rigid abutment which should prevent to a large extent the emerging deformations. For this purpose a box-shaped abutment was designed with a total of 8 inclined bored piles with 1,20 m diameter. The potentially still emerging changes in length should be distributed over a considerable length and in deep underground layers. In order to achieve this, the first part of the drag plate was rigidly connected with the load bearing structure and also constructively tensioned in the wings. In this way the sealing can also be applied beyond the frame corner to the end of this first part without the need to come up with special solutions for the movement joints. The movements are conducted by this construction away from the statically high exposed structure elements to the end of the first part of the drag plate.

The particularity of the bridge construction is the connected second part of the drag plate which was built as a special, longitudinal flexible drag plate. In order to be able to conduct the discrete movements continuously in the open space, a spring has to be added on both ends of the bridge in structural sense, whereas its rigidity has to be adjusted in such a way as to achieve a continuous dilatation throughout the length of the spring. The length has to be chosen so as there is no more shifting at the free end of the spring (Hartl 2011)

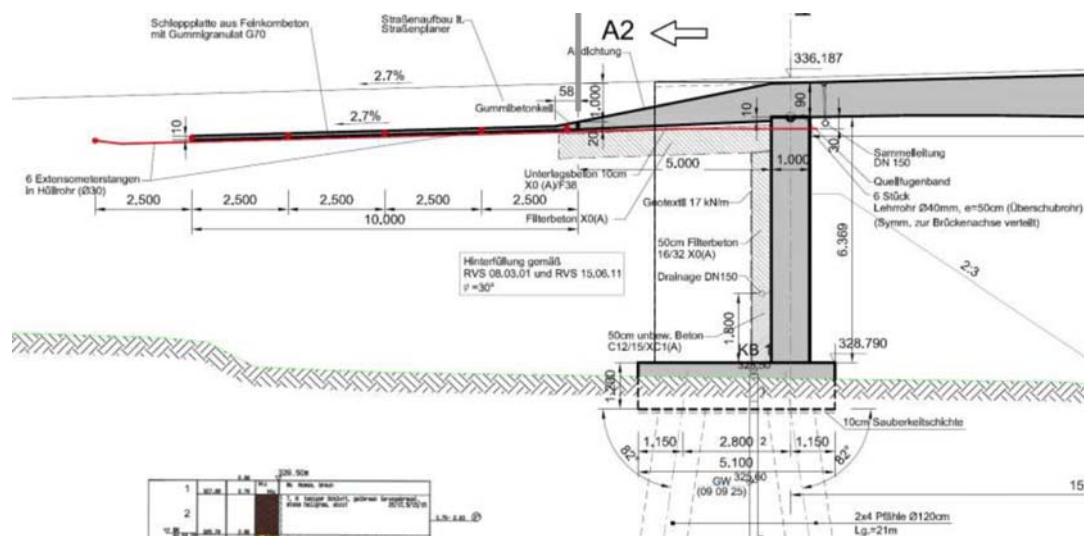


Figure 11. Longitudinal flexible drag plate made of rubber concrete

During the construction it became clear that for this purpose reinforced concrete was much too rigid and geomembrane much too soft. The solution was to replace the stone aggregate in a conventional standard concrete by rubber granulate (for example old tyres) which allows for the production of a concrete with very low E-module. The longitudinal stiffness can be adjusted through the reinforcement. Additionally cross-brackets were provided for in the normal concrete below the rubber concrete in order to hold the reinforcement in place (Hartl 2011, 2013).

In order to verify the assumptions of the statical calculation, as well as the functioning of the drag plate, a measuring system was installed in the construction. In this way it could be shown that the movements measured – despite the stiff abutment construction – are quite similar with those of a conventional bridge construction. This means that in practice a rigid abutment cannot be achieved with reasonable costs and on conventional underground, with the consequence of defining it also in Austria as a special case.

The measurements at the construction show that the bridge functions impeccably without expansion joints, especially in the transition area to the open space. The movements are absorbed in the carriageway surface due to the extensive longitudinal distribution exclusively via the roadbed cuts and cast joints. The basic design idea was thus confirmed by the measurements.

## SEITENHAFENBRÜCKE

The Seitenhafenbrücke is in Vienna and is part of the Freudenuer Hafenstraße, crossing an arm of the Donaukanal. The bridge was designed for road, pedestrian and bicycle traffic. The total length of the bridge is 128,69 meters divided in 5 fields and the width 15 meters. The abutments are not aligned at right angles with the road axis. The client of this investment was the Wiener Brückenbauabteilung MA 29 (Vienna Bridge Construction Department). The design was performed by the Austrian engineering office PCD, whereas the testing and conception of the monitoring system was carried out by Schimetta Consult.



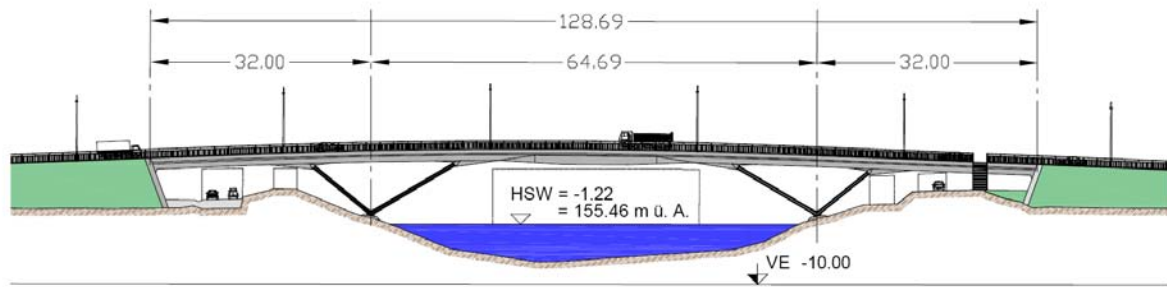


Figure 12. Construction Seitenhafenbrücke (PCD 2009)

The load bearing structure was meant to be a mix of functionality, shape and cost-efficiency. The load bearing structure itself was built as a solid construction. The support of the bridge structure was realized with steel columns which next to the bearings were arranged in pairs. They ensured a slim outline of the pier structure. In the mid field, the carriageway slab opens up in a ribbed slab with 8 sidewalls. The flat load bearing structure is dissipated by a hierarchical deviation of the loads from the carriageway into slim, transversal braces to the abutment areas. At the top there is a uniformly running edge beam (PCD ZT GmbH, 2010).

In order to further improve the wing-span relation between the main field and the lateral field, which considerably favoured the statical behaviour of the bridge, both abutments were deliberately placed at the back. This extension of the lateral fields also avoids local collision with the retention wall on the left bank and with the main collector on the right bank. The bridge was made without bearings and extension joints in form of an integral structure with flexible abutments (PCD ZT GmbH 2009).

The particularity of the bearing structure is connected to the application of the concept of the flexible abutment in the design phase. This means that the basic idea is that between a self-supporting embankment (in this case a skew embankment with 70° angle of slope and geomembrane reinforcement) and the abutment soft inlays are used. These soft inlays should allow for a zero-stress expansion in summer and shortening in winter. A layer of EPS was also applied. Additionally – in order to increase the effect of the elastic foundation – a coating using soft inlays was also performed in the area of the bored piles. On the upper 4 m of the piles below the pile grate a 3 mm thick steel jacket pipe was drilled which was also coated on the inside with EPS.



Figure 13. View of the Seitenhafenbrücke

During the design phase, an imposed stress resulting from the earth pressure was not much taken into consideration, as agreed with the geologist and the test engineer, which made it possible to achieve – for Austrian realities – an extremely long integral structure.

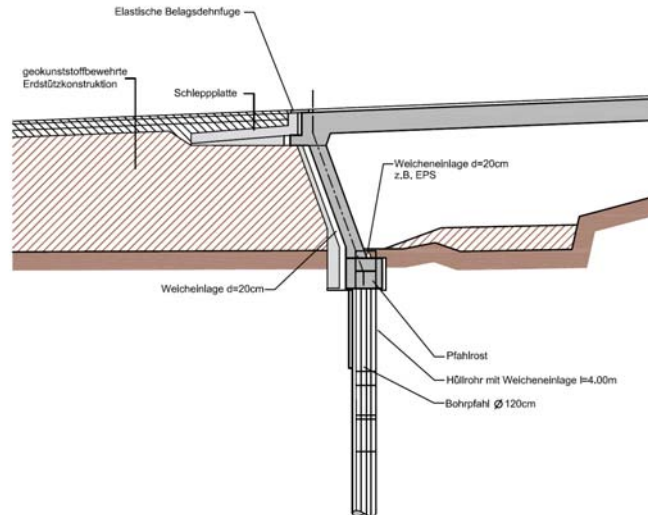


Figure 14. Detail of the abutment construction (PCD 2009)

Already during the design stage the building owner decided to have the assumptions of the statical calculation verified after construction with the help of a monitoring system. The tasks in terms of the configuration of a monitoring system for the Seitenhafenbrücke were thus mainly as follows and were meant to ensure a better assessment of the bridge behaviour over the time:

- inspection of the projections for the concept of the “flexible abutment” with elastic inter layers behind the abutment with fiber-reinforced and self-supporting embankment. This concept makes it possible to neglect the earth pressure loading when performing the calculation. For this purpose earth pressure sensors were placed behind the abutment.
- performance of laser measurements of the length variations of the load bearing structure in order to be able to correlate the results of the earth pressure, as well as of the vertical bearing structure deformation.
- determination of the statical (vertical) deformations of the structure with the help of an electronic hydrostatic level to see the seasonal progress at selected points and comparison with the assumptions of the statical calculation.
- behaviour of the flexible steel columns to see the seasonal progress especially their dislocation through measurement of the inclination.
- determination of the structure temperature to see the seasonal progress as a basis for the interpretation of all other parameters.
- automatic data storage through a measuring station at the bridge.
- data transfer via an internet connection with rapid possibility for presentation of the results also without complex special programs.
- current reporting concerning the measured results and comparison with the assumptions of the statical calculation.

Based on these requirements a tailored monitoring system was designed which falls back on well-proven components. For this purpose a separate detailed planning was performed containing the mounting positions of the sensors, a cable route plan and a detailed drawing of

the position and execution of the base station, which was integrated in the planning and inspection plan. By its integration during the design phase the later on-wall mounting could be avoided and the architectural appearance of the bridge construction was not affected. During the execution the constructor considered ductworks for cables, junction boxes, assembly shafts and a niche for the base station. A lockable steel door was made for the base station which was integrated in the inclined abutment wall in full accordance with the architecture. The early consideration of the monitoring system also made it possible to include it in the tender together with the construction part, which contributed to keeping the investment costs very low compared to the total production costs. For this purpose a tendering documentation was elaborated and the respective positions were integrated into the contract specifications. The data so far collected by the monitoring system in place have confirmed the assumptions of the statical calculations to a wide extent and allow thus for a better and more secure understanding of the structural behaviour of these integral constructions. This application also shows that monitoring systems are a useful tool for our building stocks in terms of the observation of their state and for future design reliability.

## **CONVERSION OF EXISTING STRUCTURES IN INTEGRAL BRIDGES**

On occasion of the servicing of conventional bridges it is often ascertained that the construction related vulnerable points like bearings and expansion joints become soon the reason for further complaints. In this context it makes sense to convert such bridges in integral constructions – especially when it comes to the numerous small structures within the secondary roadway network with lengths not exceeding 40 m. There is the advantage that the maintenance costs are reduced as a result of the elimination of the joints and that, following the change of the structural system, the load capacity can be increased, if need be.

One positive issue in this context is the fact that when servicing these structures the time-dependant concrete behaviour does not have to be specially considered any longer, given the usually high age of the construction. During the conversion of such structures one could consider the following aspects:

- the removal of the existing joints is not necessary as they can stay in the bridge and be covered with reinforcement and concrete.
- use of self-compressing concrete or grout for the filling of the bearing gaps.
- if possible, the closed linkage between the bearing structure and abutment (grouting of the bearing gaps) should be performed on cold weather conditions.

In the last couple of years it was possible for the bridge upholder to achieve significant reductions in cost, especially in what concerns the numerous small bearing structures within the roadway network. The experience gathered so far in relation to the conversion of bridge constructions already performed has fully confirmed this approach.

## **SUMMARY**

Integral constructions still have very much potential for future developments meant to make our building stocks more sustainable and cost efficient throughout the life-cycle of a building. Step by step, larger and more demanding structures have been built in Austria in recent years which – also based on integrated measuring systems – allowed for achieving very interesting results with further potential for developments and innovations.

It is exactly the field concerning the transition area from the bridge to the open space which has gained even more attention in order to further push certain developments like for example the rubber concrete drag plate.

Besides the aspiration to build larger structures in integral construction, the conversion of smaller, older structures in integral constructions is also a field with a large future potential which we have to continue to pursue.

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