CLOUD TOWER
CONSTRUCTION OF STEEL AND CONCRETE PLATES

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Description of the Structure

In the park of castle Grafenegg near Vienna a pavilion for grand orchestra was established in 2007 (Fig. 1). The construction is composed of reinforced concrete walls and plates in the lower part and covered by a folded plate in steel. The 23-m-high structure is placed in a natural depression giving place for an auditorium of 1670 persons. Clearly distinguished from the natural terrain by their geometry, stage and auditorium nonetheless merge fluidly with the topography of the site.

The concrete part is composed of walls and plates, inclined in various directions. The concrete is exposed to sight and weather, no thermal insulation, sealing or plastering has been applied. Thus the construction process was considerably demanding for the construction company.

The stage-roof is made of steel and glass, reflecting the surrounding sky and trees. The steel plates are stiffened with ribs and welded in position. The weight of the roof is about 80 tons.

Fig.1: Cloud Tower near Vienna

First Design Approach of the Connection between Steel and Concrete

The connection between the steel construction and the concrete part is of special interest in this structure. The first idea was to fix the steel part on the concrete walls with shear studs. No slip between the two parts was allowed. Integral structures are generally simpler to construct and need less attention and effort in maintenance and servicing. Of course the combination of two different materials exposed to environmental impact implies other difficulties. Especially the temperature difference between steel and concrete are expected to cause large stresses in the interface. As the thermal conductivity of steel is larger than that of concrete and as the steel plates are thinner than the concrete slabs, the temperature in the steel part will rise faster than the concrete's temperature with the sun rise in the morning. Also the maximum temperature during the day will differ quite significantly between the two materials.

Thus a reliable estimation of the temperatures is important for the design. In a first step a value of 15 K given by EN 1991-1-5, 6.1.6 (1) as temperature difference of different parts of a tied arch bridge can be assumed. However it is known that steel under direct sunlight might heat up enormously and the value of 50 K is not rarely used for the design of bridge bearings.

A value in between these two can be found in EN 1991-1-5, Table 5.2: The maximum temperature for South-West facing elements is given as 30 K above air temperature for light coloured surfaces and

42 K for dark coloured elements. For the grey colour of the steel plates of the considered structures' roof a value of 36 K can be estimated although the orientation is South-Est instead of South-West. The concrete structure is exposed to sun shine but it heats up slower than the steel, especially since the concrete is shaded by the steel plates in the morning sun. In the first approach the maximum concrete temperature was assumed to be the same as the air temperature. Thus the maximum temperature difference between steel and concrete along the interface was determined to be 36 K.

That difference in temperature led to large but treatable stresses in the two parts. The compressive stress in the 10-mm-thick steel sheet under temperature difference of 36 K was approximately 7,5 kN/cm² along the interface. Stiffeners were needed along the connecting joint to prevent buckling of the steel part and an increased amount of reinforcing steel has to be provided in the concrete part along the interface to control crack widths, though the tension from temperature alone is only about the tensile strength (3,5 MN/m²). The resulting forces would have to be transmitted from the steel to the concrete.

Actual Design of the Interface

In combination with the uncertainty of the actual temperature differences, it was decided in close collaboration with the steel contractors engineer Bollinger and Grohmann to change the details to sliding connections. Eventhough usually sliding connections are more difficult to develop, in this case the small loads where an advantage, especially since the buckling of the plates could be prevented. (Fig. 2)

The steel structure is designed like a ship with plates and stiffeners. The plates have a thickness of 1 cm to 1,5 cm and the stiffeners a regular size of 200mm x 20 mm. The load bearing behaviour is a hybrid of a bending and a shell structure. Special focus had to be put on the corners since not only the plates had to be fixed, but the stiffeners being placed 20 cm from the plate corners as well.

Awards

The Cloud Tower was awarded the Building Prize of Lower Austria in 2007 and the "Österreichischer Bauherrenpreis" in 2009.

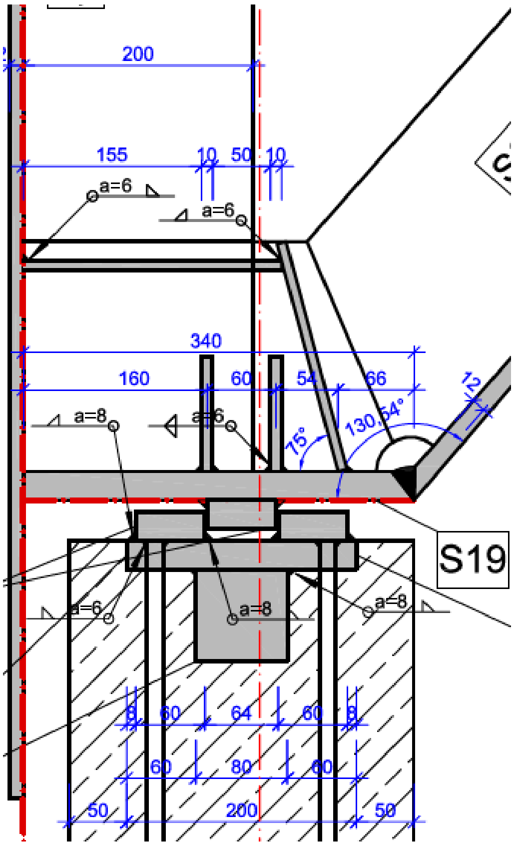

Fig. 2: Vertical section of bearing

References

EN 1991-1-5:2003 + AC: 2009, Actions on structures – Part 1-5: General actions – Thermal actions, German version, Beuth Verlag, Berlin, 2010

BERGMEISTER. *Wolkenturm Grafenegg* [online]. http://www.bergmeister.eu/bm/upload/datenblaetter/05-061-D_Wolkenturm_Schlosspark_Grafenegg.pdf (last visited 26.05.2014)