DRAUGHT LOSSES
Changes and Consequences

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Martin Breddermann

Martin's work as a civil engineer ever since his graduation in 1992 has focused on industrial structures such as chimneys, containments and refractories, where restraint and thermal impacts dominate.

After his adjuration as a publicly certified expert for industrial chimneys in 2015, he started to run his own consultance office together with his partners Elisabeth Brylla and Holger Leszinski, BREDDERMANN+PARTNER, Bochum, Germany. All three managing partners are actively participating in related working groups of the professional associations.

Holger Leszinski

Since his graduation in 2002 Holger has been preparing numerous expert reports in the fields of industrial facilities, in particular refractory construction. His experience covers structural analyses regarding close-to-reality material behaviour, thermo-mechanical computation of industrial furnaces as well as development of associated software. Holger and Elisabeth both are managing partners of BREDDERMANN+PARTNER since 2016.

Elisabeth Brylla

graduated at the University of Dortmund as civil engineer in 2001. After graduation she was managing partner in a family-run surveyor's office with the emphasis on inclination and damages on buildings caused by coal mining in the Ruhr area. Since 2007 she has been working in the field of industrial construction including structural engineering, inspections and assessments of chimneys and further industrial structures. She is licensened as examiner for structural inverstigations, with a further qualification for nondestructive structural tests

The design of a new chimney gives the freedom to fulfill all boundary conditions: Gas velocities are optimized in terms of back flow and down wash, all surfaces and cross-sections are smoothened to reduce draught losses to a minimum and a height over ground is chosen to have natural draught operate the system without additional induced ventilation.

Apart from that, in existing systems draught calculations are necessary whenever there are any changes to be made within the duct system, consisting of the mostly horizontal part – starting at the source of the waste gas, i.e. the vessel or furnace – and ending after the vertical part inside the liner of the chimney into the surrounding at its mouth. Changes in here by means of gas flow calculations may be because of several reasons such as

- change of the gas volume flow, e.g. due to addition of new furnaces,
- change of the gas temperature, e.g. due to the transition into wet stack operation,
- change of the duct geometry due to reconstruction.

The above list cannot be complete, but short examples of case studies are given to identify and discuss their consequences and to sensitize engineers and clients for their likely causing of problems.

BASICS of gas flow calculations include evaluating of a lot of different parameters. The way to handle them for the purpose of chimneys is described in CICIND's Manual for Thermofluodynamic Design and in DIN EN 13084-1 and will not be deepened in here. Both are based on fluid dynamics and with that on Bernoulli's equation, saying that the sum of geodetic, static and kinetic pressure within the gas flow is constant.

To calculate the static pressure conditions inside the system, there is the geodetic natural draught, giving the available (under-)pressure and there are several resistances, which sum up from the mouth all the way to the source. If the resistances get too high, positive (over-)pressure will be induced which might harm the structure of masonry or leaking liner constructions.

The chimney effect produces the theoretically available natural draught – which is defined by the difference in the densities of the surrounding air and the flue gas multiplied by the effective height from the gas inlet up to the mouth of the chimney –and controls gas pressure inside the duct system starting at the furnace or vessel.

This available draught is reduced by the pressure resistance along the flue gas carrying duct system. Draught losses herein include kinetic pressure changes due to change of velocity following Bernoulli's law as well as irreversible pressure drops due to friction and form resistance by the formation of turbulences disturbing the jet.

The formulas of EN 13084-1 for the available draught and the resistances are shown in figure 1 without further explanation.

CASE EXAMPLES

for some common tasks are given in the following, including

- Modelling of the computational system and
- Increase of the gas volume flow of a chimney with historic liner design, Cases 1 and 2,
- Conversion of a modern chimney into wet operation, Case 3, and
- Changing of the historical tunnel system below mill floor, Case 4.

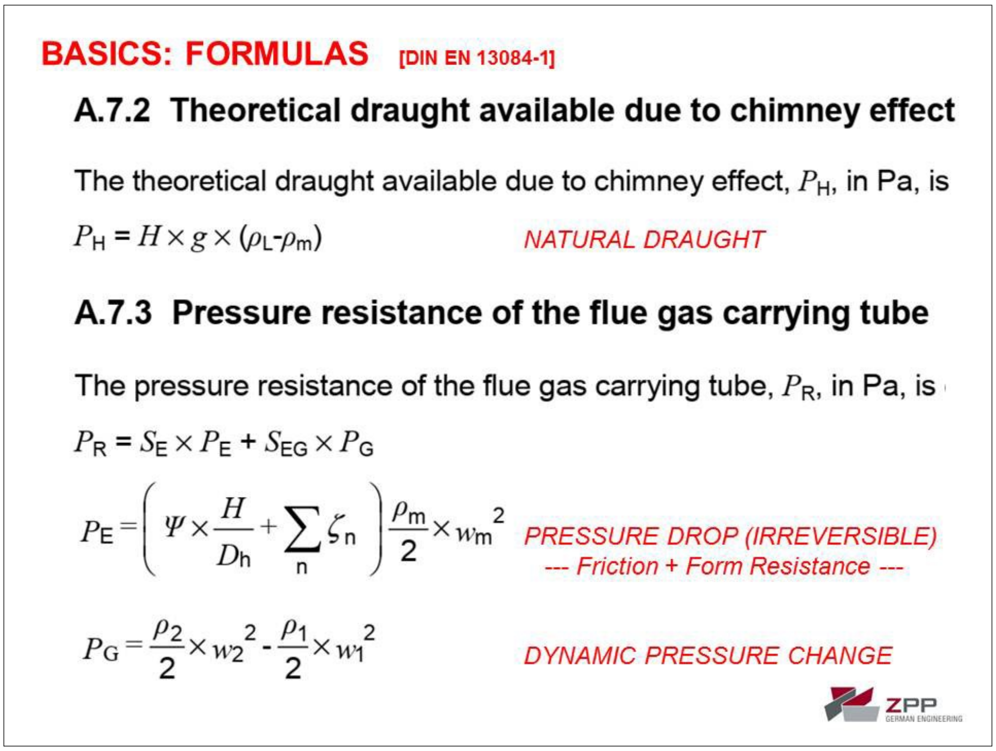

Figure 1

CASE 1: Detail Modelling of the Computational System, figure 2

The capacity of the steel mill shall be expanded by adding a new furnace to his old-fashioned 50m high chimney. In the first guess, the furnace builder predicts that the chimney is capable to discharge 50 percent more exhaust gas than before with very few pressure losses at the entry of the chimney.

To come to this answer, the builder assumed a smooth surface of the old masonry liner and furthermore did no detailing of the structure of the gas carrying tube at all, using a fictive constant diameter (which matches somewhere in the upper part of the liner) but neglecting the loss of cross section over height and neglecting the cross sections of the various transitions of the inner liner.

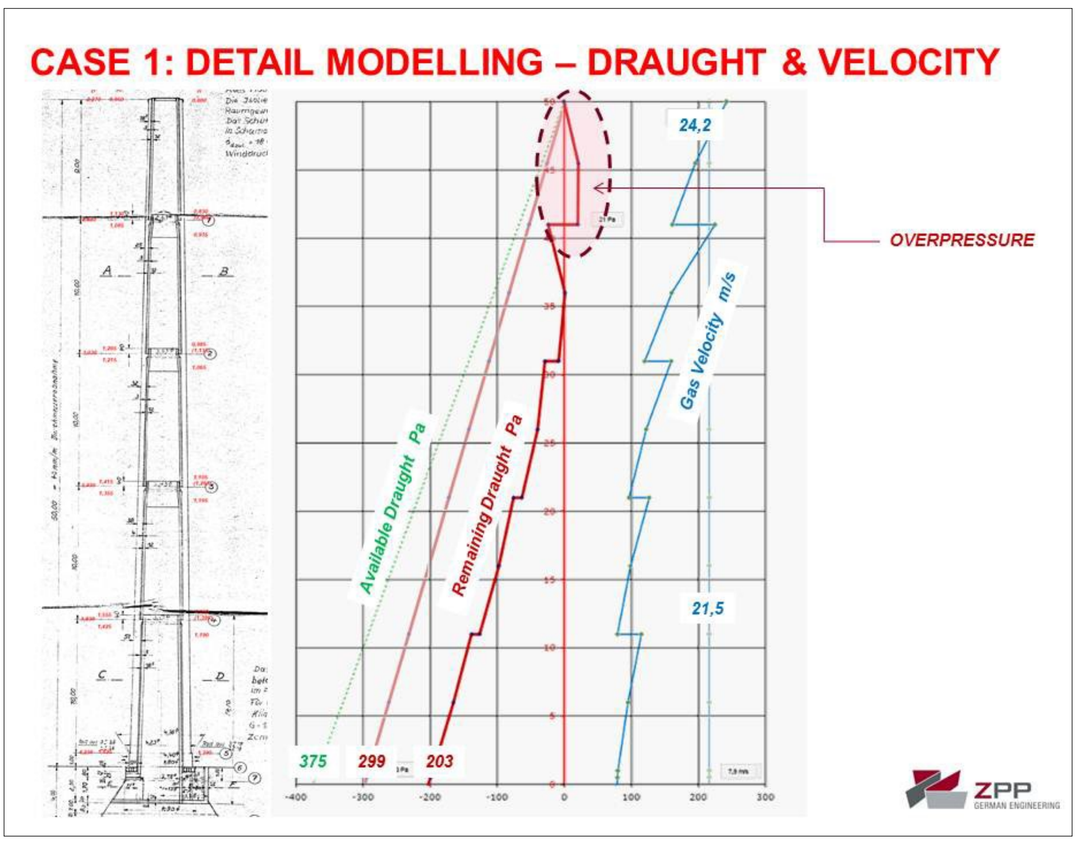

Figure 2

The more detailed computation (following the actual geometry of the liner) revealed more pressure losses at the entry. Here, the resulting energy height defined by Bernoulli and corresponding to 203 Pa (2.0 mbar) gets to 27.1m which means a loss of 22.9m out of 50m, or 46% of the theoretically available draught corresponding to 375 Pa.

Even more important to judge the possibility of expansion is the expected overpressure in the top liner section which cannot be accepted in the masonry structure.

CASE 2: Doubling of the Gas Volume Flow, figure 3

Within the same project as in case 1 the actually planned increase of operation means to double the waste gas volume by adding two new furnaces to the mill. With the first opinion of the furnace builder in mind, it was assumed that "a few more losses" must be expected but are acceptable.

The completion of the study of case 1 – using the detailed computational system including the roughness and the loss of cross section of the conical shape over height and including the transition areas of the inner liner tube sections – was carried out to compare the actual operational conditions and the planned expansion of capacities.

As expected, the study revealed serious overpressure almost over the complete height down to the inlet into the chimney with remaining draught only in the lowest liner section. The energy height at the inlet elevation calculates to 10.3m (77 Pa), being a loss of almost 80% out of 50m. The overpressure in the top half of the liner with 90 Pa (0.9 mbar) is even higher than the remaining draught at the inlet of 77 Pa (0.8 mbar).

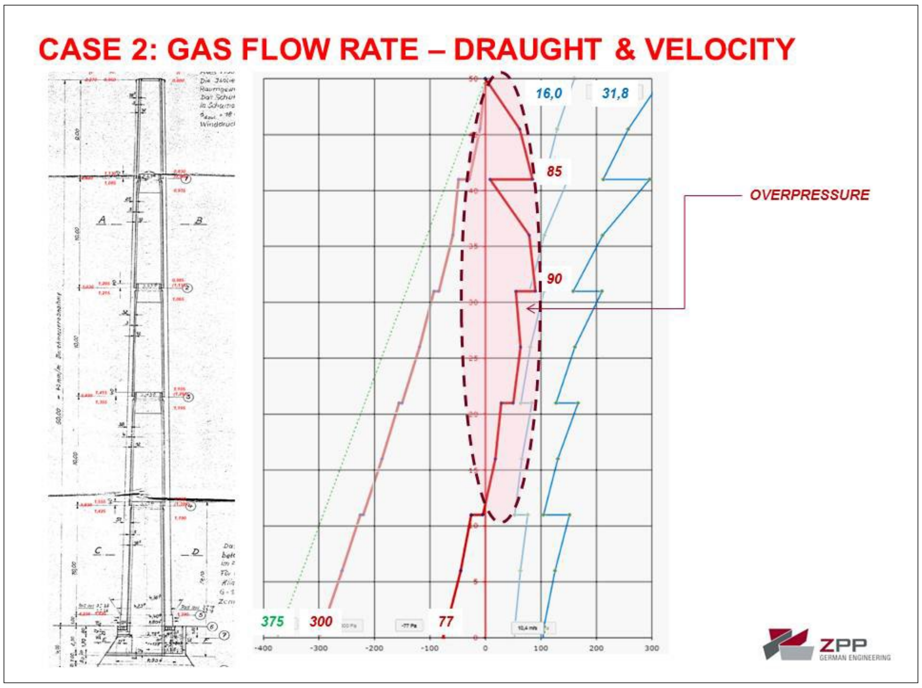

Figure 3:

On the other hand, the actual operation did not show overpressure within the system, which proves the original layout to be adequate for this, serving a draught of 300 Pa (3.0 mbar) to the horizontal duct system below mill floor.

Cases 1 and 2 emphasize the strong dependency of draught losses to the flow velocity within the system. As the formulas for the pressure resistance of the flue gas carrying tube show, each term includes the squared flow velocity as a multiplier.

CASE 3: Gas Temperature Decrease, figures 4 and 5

Re-heating of the flue gases after wet flue gas desulphurization at a power plant was cancelled once the public regulations allowed so. With this, the attached modern chimney with an acid resistant, sectional brick liner was transmitted into a "wet stack" where the water content raises to saturation and the gas temperature levels from some 120 °C to the associated water dew point of 66 °C.

Although raising water content makes exhaust gases relatively lighter, the influence of the drop of temperature is much more relevant: in the end the actual gas volume flow is reduced resulting in lower gas velocities with down wash effects and even ice formation at the chimney mouth.

Decisive for the actual behavior of the exhaust flow is the lower available natural draught, determined by the higher density of the cooler gas. Draught at the inlet drops from 363 Pa (3.6 mbar) to 196 Pa (2.0 mbar) which obviously is still is suitable for the operation of the vessels since changes were implemented some years ago.

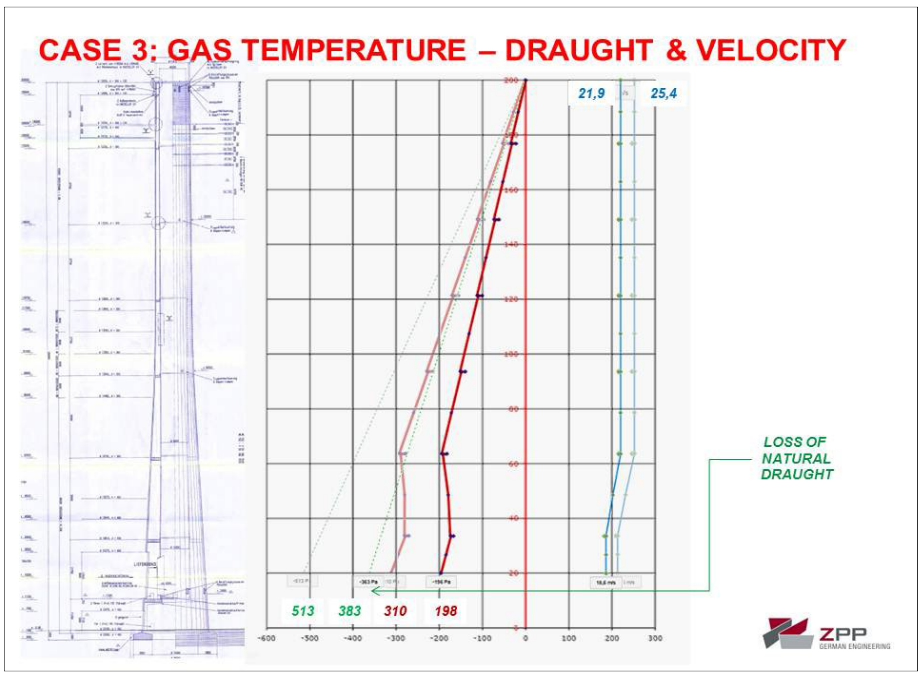

Figure 4:

Undesired consequences of the new wet stack operation are rather the permanent shortfall of the dew points for water and acid combined with the resulting high amount of liquid. Furthermore, the drop of the gas exit velocity from 25.4 m/s to 21.9 m/s slightly increases the risk of down-wash to the outer surfaces close to the chimney mouth. Since down-wash is a function of the velocities of wind and gas, its occurrence must be expected at lower wind velocity – which simply means: more often and over a wider area of the surface.

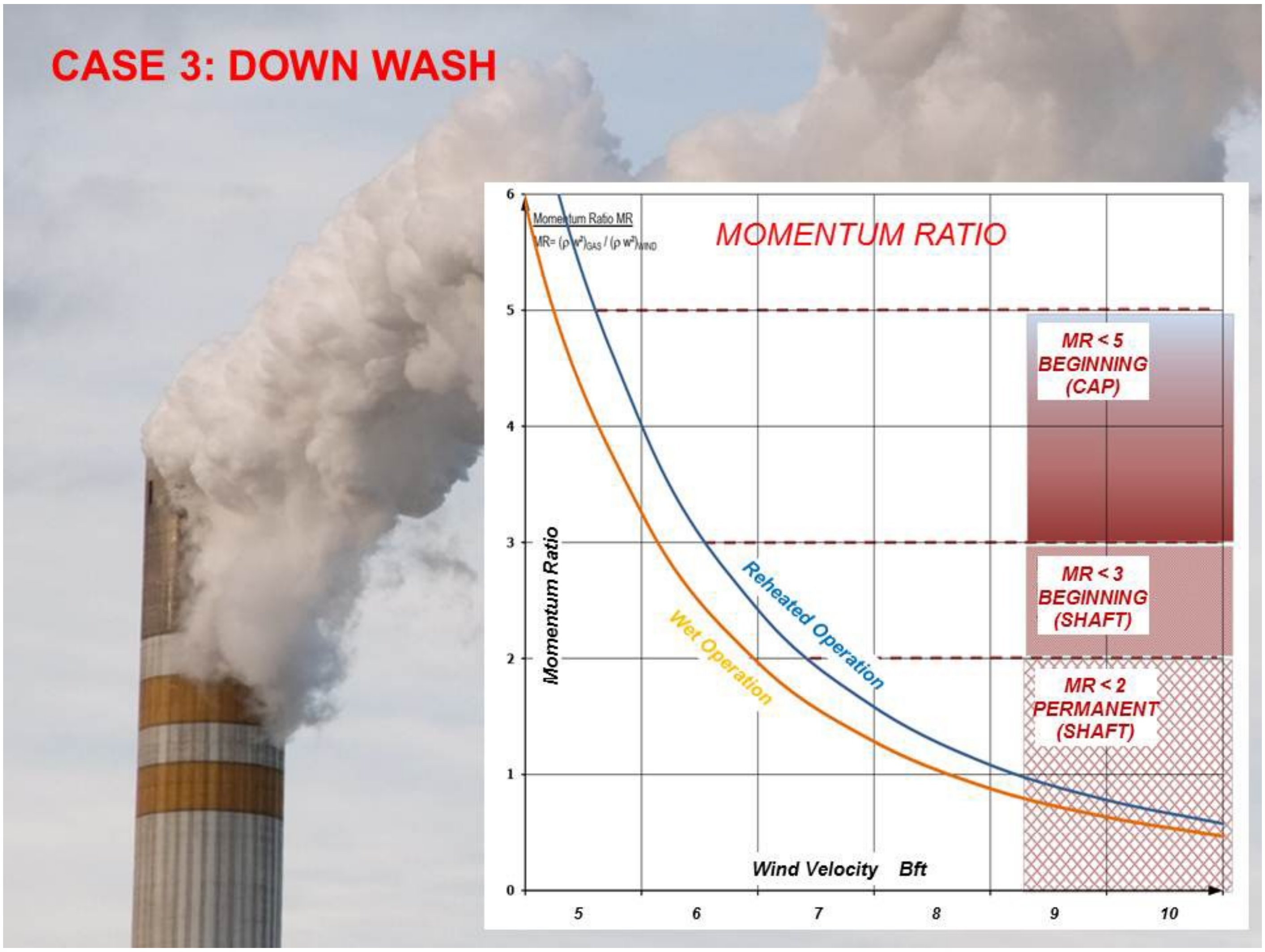

Figure 5

CASE 4: Duct Geometry below mill floor level, figures 6 and 7

The old flue gas carrying duct system contains of various areas with different cross sections and several bends and elbows up to 90° degree in horizontal direction, heading to an old 65m high masonry chimney. Necessary construction works on site cross the duct below mill floor, cutting and reducing its cross section to less than the half in a sharply limited area. The crossing is located in one of the bigger sections but very close to a sharp turn downstream the flow.

Common tables and formulas for fluid mechanics do not specifically deal with the cross sections and deflections and their arbitrary combinations of the old tunnel system that grew over decades. Since, for example, the sudden reduction of the cross section effects the loss of its upper part, it was not clear if loss values for the reduction, the vertical turns and the extension should be added, or if the whole area behaves like a orifice – or if none of them is correct because of the diverse changes of flow direction in and right behind the crossing.

Local CFD analysis helped to verify the assumptions and to improve them interactively. In the end, the loss values for this specific problem came out to be very close to the values tabulated for sudden (centered) changes of the cross sectional areas upstream and downstream plus the following elbow. Here, the changes of the vertical flow direction to pass underneath the obstacle seem to be without influence.

CONCLUSIONS

of the above can be summarized for existing systems subject to changes as follows:

The available draught is determined by the effective height and the gas density solely. If there are no major operational changes, these values can hardly be influenced by the designer within existing systems.

Draught losses on the other hand derive from three main sources: friction and form resistance (both irreversible pressure drops) and kinetic pressure changes due to change of velocities. In present ducts friction may be reduced by cleaning and smoothing the surfaces, but it has to be doubted, that those losses are responsible for malfunctioning. Much more promising measures could be the reconstruction of discontinuities to minimize turbulences, if possible.

In any way, it always has to be kept in mind that all draught losses on the path to the chimney's mouth go with their respective squared gas velocities. If those cannot be controlled, it will hardly be possible to influence the overall behavior.

If an existing system needs to be changed for some reason, the final question will always be if the plant will continue to work well afterwards. Whether it is the chimney or the ducts or the vessel/furnace that are to be modified, careful thermo-dynamical analysis of the gas flow is needed.

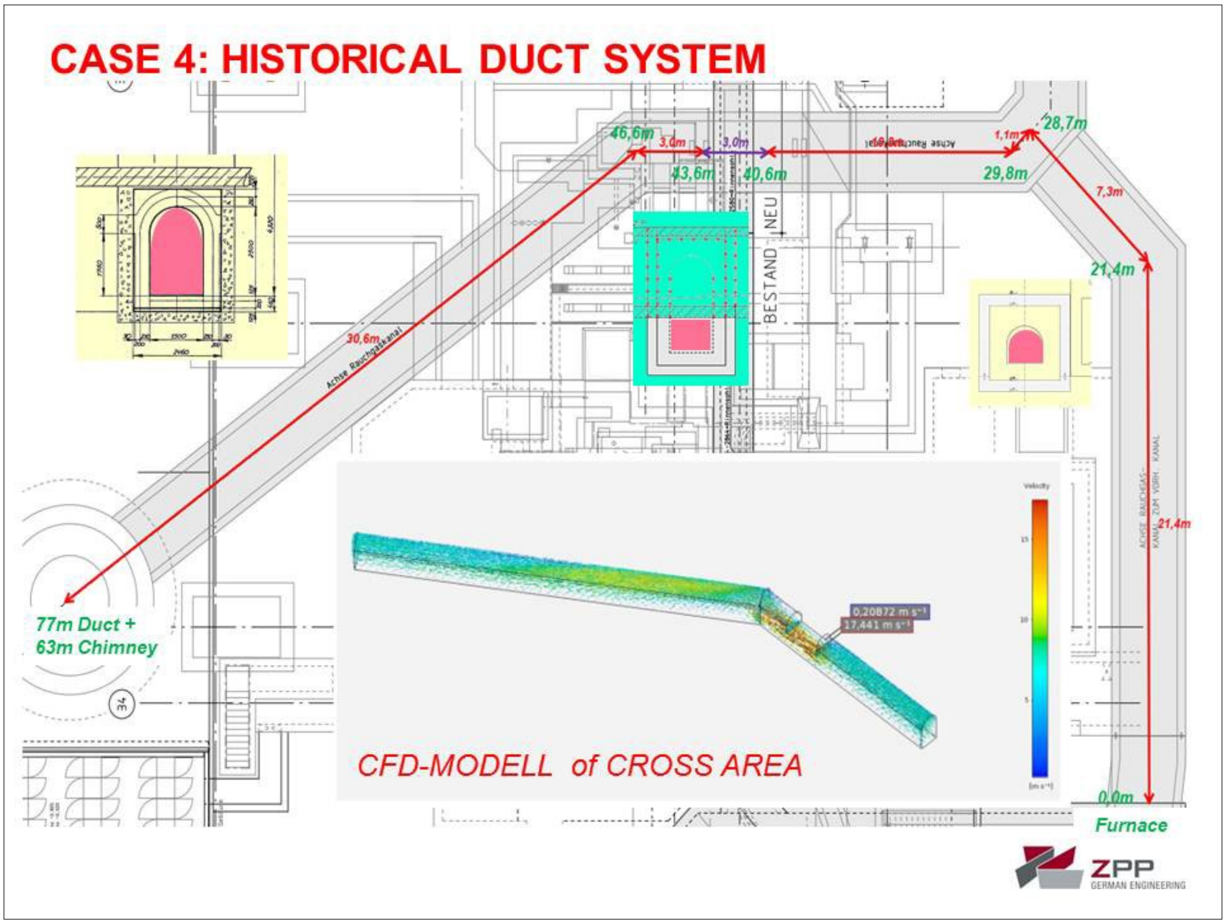

Figure 6:

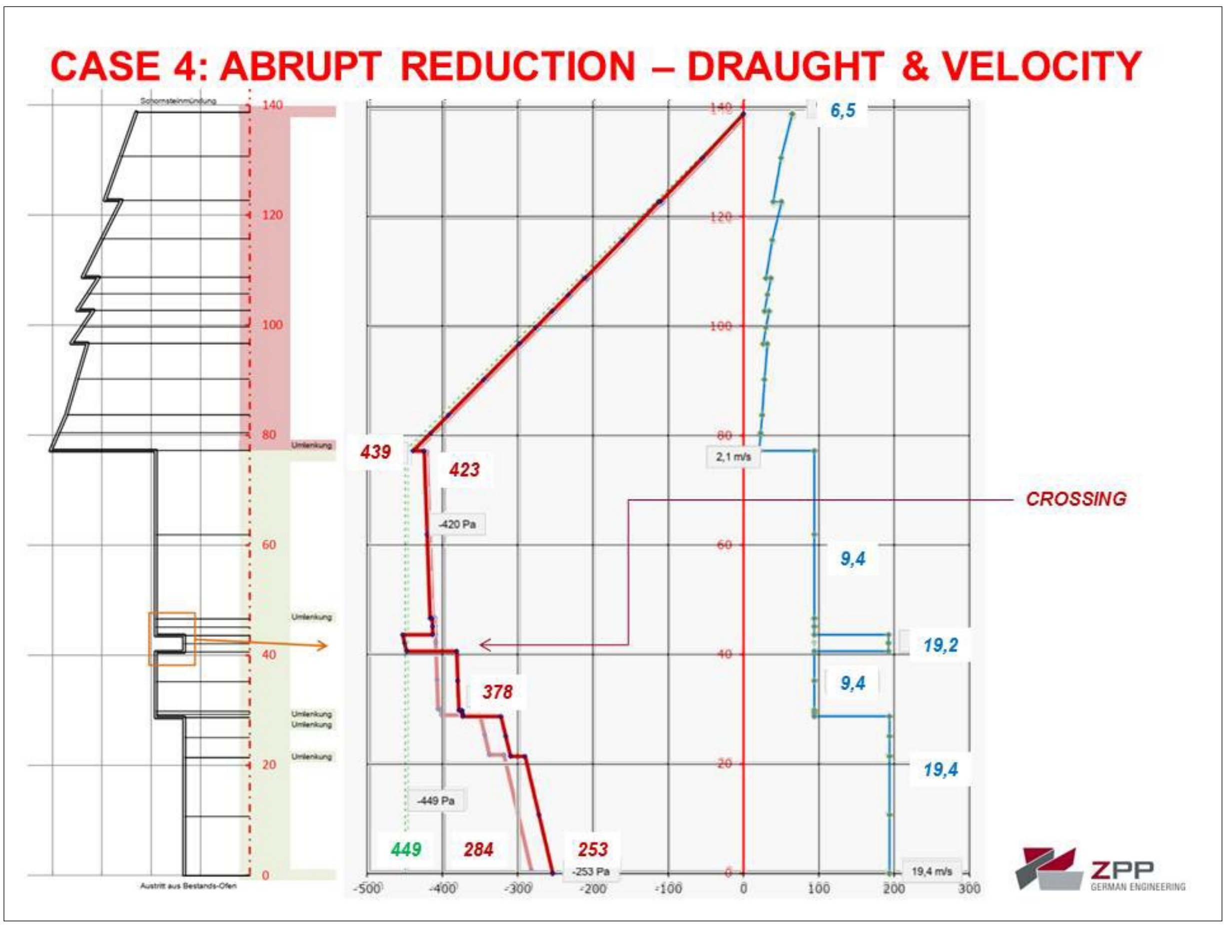

Figure 7