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BLAST-DEMOLITION OF COOLING TOWERS IN CONVENTIONAL AND NUCLEAR POWER PLANTS

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ABSTRACT

After decommissioning of nuclear and coal-fired power plants, the demolition of the cooling tower is a challenging task with significant effort. For economic and environmental reasons, blasting is an interesting possibility. This paper serves an overview about the required steps in the planning phase. More detailed information can be found in adjacent paper in the same session.

INTRODUCTION

As part of the energy revolution in Germany, the phase-out of nuclear energy until end of 2022 and coal-fired energy until 2038 is decided. In this context, the decommissioning of 27 nuclear and 106 coal-fired power plants is planned or has already been executed. Besides mechanical demolition with grab excavators and chisel robots, blast demolition is an economical alternative, especially for tall structures such as smokestacks and cooling towers. In addition, the exposure to dust and noise can be reduced considerably, due to the short deconstruction time. In Germany, natural-draft cooling towers have already been successfully brought down 59 times by means of collapse blasting. Currently, the blast demolition design of further three cooling towers of nuclear power plants and two cooling towers of coal-fired power plants is in progress.

In coal-fired power plants and nuclear power plants, hyperbolic natural-draft cooling towers with heights between 55 and 150 m are usually operated. They consist of a reinforced concrete shell with a wall thickness decreasing with height, which is supported by annularly arranged columns on ring or single foundations.

Blast demolition is an exact and safe procedure, if planning and execution is carried out by well-educated and experienced engineers respectively demolition experts. The design phase is subdivided in six steps: (i) Chose of blasting and collapse strategy, (ii) verification of collapse safety, (iii) verification of structural safety of pre-weakening structure, (iv) vibration prediction and assessment, (v) detailed design of blasting and protective measures and (vi) preservation of evidence.

BLASTING AND COLLAPSE STRATEGY

In the first step of a controlled blasting demolition, the appropriate blast setup is chosen and the impact on neighboring objects is analyzed. To select the appropriate collapse mechanism and fall direction, free space for the expected impact area and the distance from the center of impact to objects worthy of protection are identified. For this purpose, existing drawings are studied and site visits are carried out (Figure 1). In addition to the choice of the collapse mechanism, the blast setup includes the dimensioning of pre-weakenings and blasting areas, which affect both collapse safety and structural integrity in the pre-weakened state. The aim is to (i) ensure the chosen fall direction, (ii) minimize blasting zones, (iii) minimize pre-weakening zones and (iv) maximize self-destruction during impact. In respect to economic reasons the minimization of blasting zones is more important than the minimization of pre-weakening zones. In order to allow for the self-destruction of the cooling tower shell during ground impact, one to three vertical slits are provided in the front area of the cooling tower shell (Figure 2) (Rapps et al, 2021). Two transverse slits are prepared on the side, which form the boundary of the blast mouth. The upper ends of the slits form the points of intersection of the tilt axis. The columns in fall direction and the lower ring girders below the vertical and the transverse slits are blasted (Melzer, 1996). In order to ensure the structural integrity of the pre-weakened cooling tower, partially webs are required in the center of the slits; they are blasted too. A comprehensive explanation can be found in (Rapps et al, 2022).

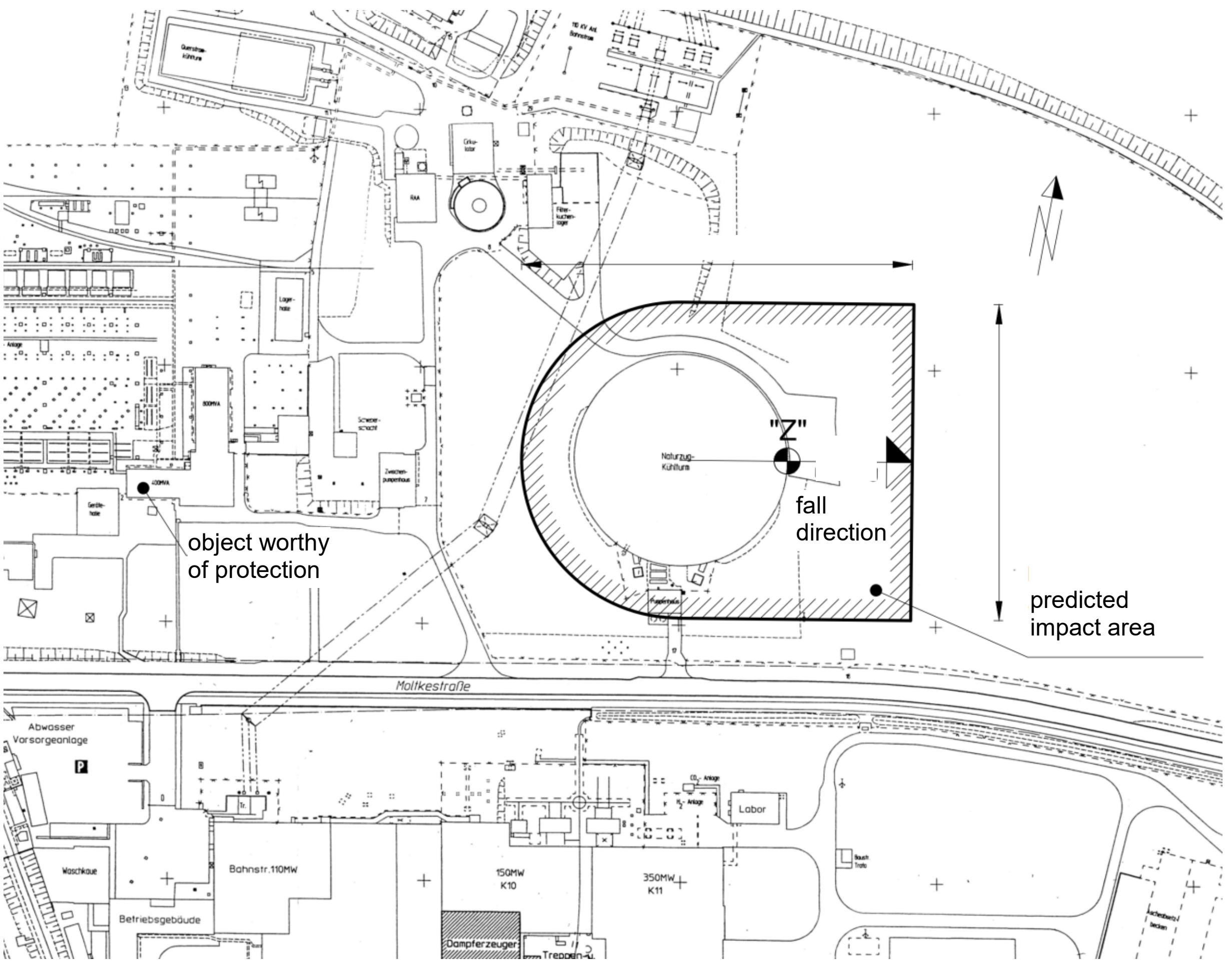

Figure 1. Blast demolition strategy in respect to free space and object worthy of protection.

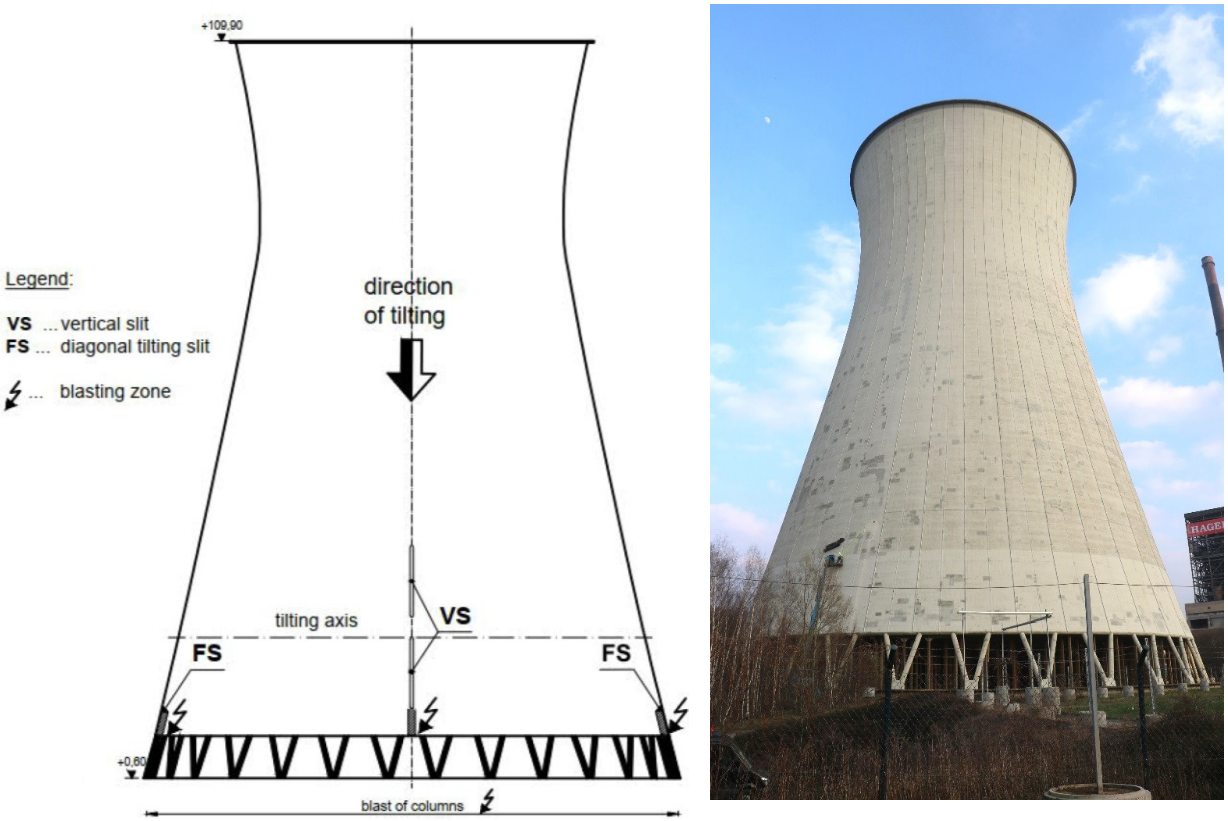

Figure 2. Typical blast demolition strategy for cooling towers.

VERIFICATION OF COLLAPSE SAFETY

In the second step, the collapse safety of the chosen blasting strategy is checked. Partially collapsed structures, where the chosen collapse mechanism failed, have to be prevented, as they are a safety problem and leads to additional costs. Usually, analytical rigid body models are applied to show, that the tilt moment is higher than the resistance moment during the whole collapse phase. Furthermore, a sufficient strength of the section, which remains after blasting, is verified.

Recently, more and more often, especially in the nuclear context, also nonlinear finite element time-history analysis are applied to check the collapse mechanism (Figure 3). For this purpose, detailed models based on brick elements for the concrete and embedded beam elements for the reinforcement are required. The material models have to include non-linear stress-strain curves, strain rate effect, fracture and erase of failed elements. First, the structure is loaded by the self-weight of the structure and afterwards the blasting zones are removed. The simulation is usually carried out with an explicit solver. For collapse mechanism simulations mean material parameters are used to demonstrate a realistic collapse behavior, fall direction and impact area. Furthermore, the influence of horizontal wind loads on the fall direction can be studied. However, an explicit collapse safety factor as obtained by analytical analyses based on the ratio of tilt moment to resistance moment cannot be determined.

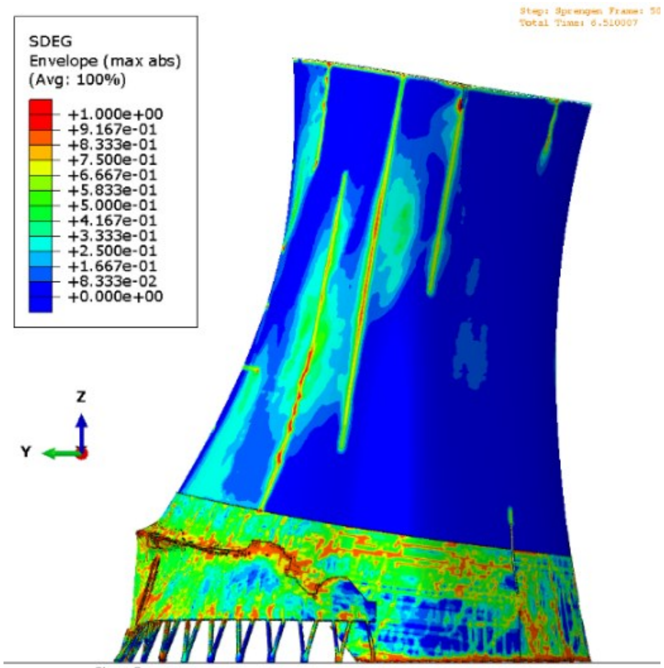

Figure 3. Collapse simulation of cooling tower by blasting demolition.

VERIFICATION OF STRUCTURAL SAFETY UNDER PREWEAKEN CONDITION

In addition to the collapse safety, the structural integrity of pre-weakened cooling towers has to be proofed for the duration between pre-weakening and blasting. The design checks are carried out for self-weight of the structure and wind load in the design load combination. Due to the limited lifetime of the pre-weakened cooling tower, the wind load may be reduced. The blasting of neighboring cooling towers is usually done with a time offset of several seconds in order to reduce the superposition of blast and impact vibrations. As the case may be, the structural integrity of the second cooling tower subject to impact vibrations caused by the first cooling tower may have to be analyzed.

The design checks are usually carried out by a global load capacity analysis according to Eurocode 2. The finite element model is built with shell elements for the cooling tower and beam elements for the columns. Non-linear material behavior is usually applied with design material parameters, where subsequent hardening of the concrete may be considered.

VIBRATION PROGNOSIS AND ASSESSMENT

The prediction and assessment of the shock and vibration impact on objects worthy of protection are substantial parts in the design phase of a controlled blast demolition. The decisive factor is not being the blast vibration caused by the detonation itself, but the shock and vibrations resulting from the impact of the collapsing cooling tower. The prediction is usually made by means of a measurement data base from previous blast demolitions of hyperbolic cooling towers. Such data base available at Wölfel Engineering includes the maximum vibration velocity of 19 cooling tower blast demolitions at 12 locations with altogether 166 measurement values (Figure 4). The statistical evaluation is based on the energy-scaled vibration measurement data and on the propagation equation according to DIN 4150-1 for falling masses. The absence of damage to neighboring objects is evaluated on the basis of the reference values of DIN 4150-3.

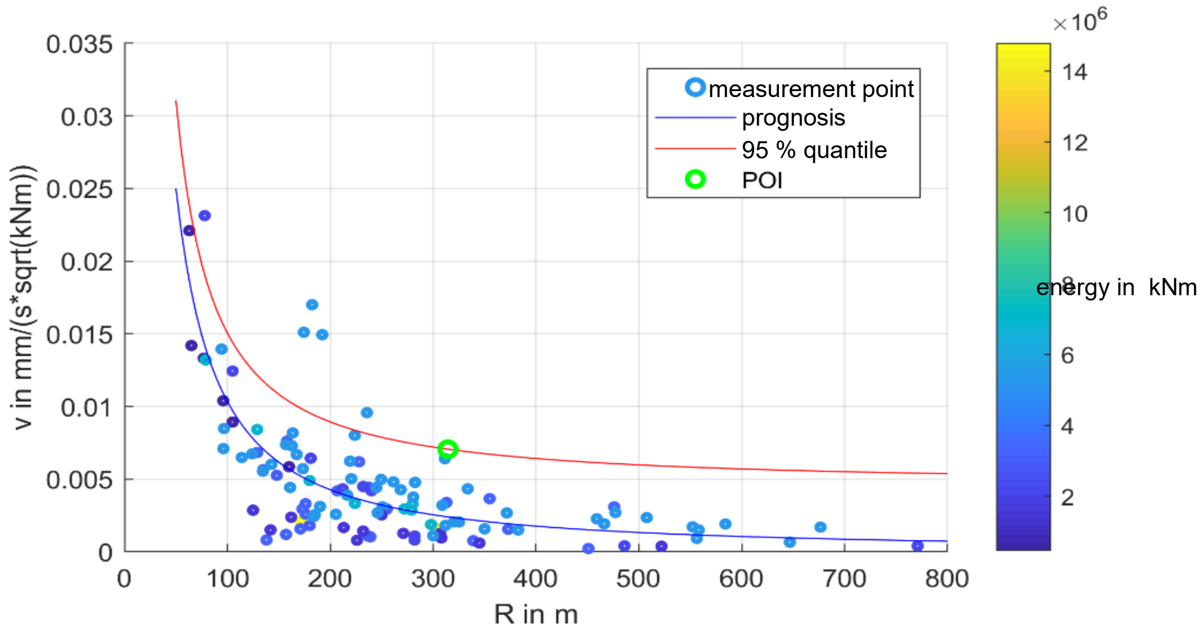

Figure 4. Vibration prognosis of maximum vibration velocities.

If a more stringent prediction and evaluation are required, e.g. for shock and vibration-sensitive adjacent buildings or in the nuclear power arena, alternative – more complex methods are applied. The design of adjacent structures and components against the site-specific design earthquake can often be used as an alternative assessment standard for demonstrating the absence of retroactive effects in nuclear power plants. However, the prediction must then contain detailed information on its frequency content in addition to the amplitude of the vibration (i.e. maximum vibration velocity). For this purpose, vibration velocity time-histories from previous blast demolitions are first scaled with respect to their amplitude so that they contain the potential fall energy of the specific blast object and the required safety level (Figure 5). The time-histories are then transformed with a transfer-function representing the vibration path from the original measurement point to the object to be evaluated. Such transfer-function is determined site-specific using a soil-dynamic FE-model; the verification of the FE-model by means of vibration propagation measurements at the site is recommended. The predicted bundle of vibration velocity time-histories at the object to be evaluated is then converted into averaged acceleration response spectra, allowing a comparison with the design spectra. For more details see (Karapetrou et al, 2022).

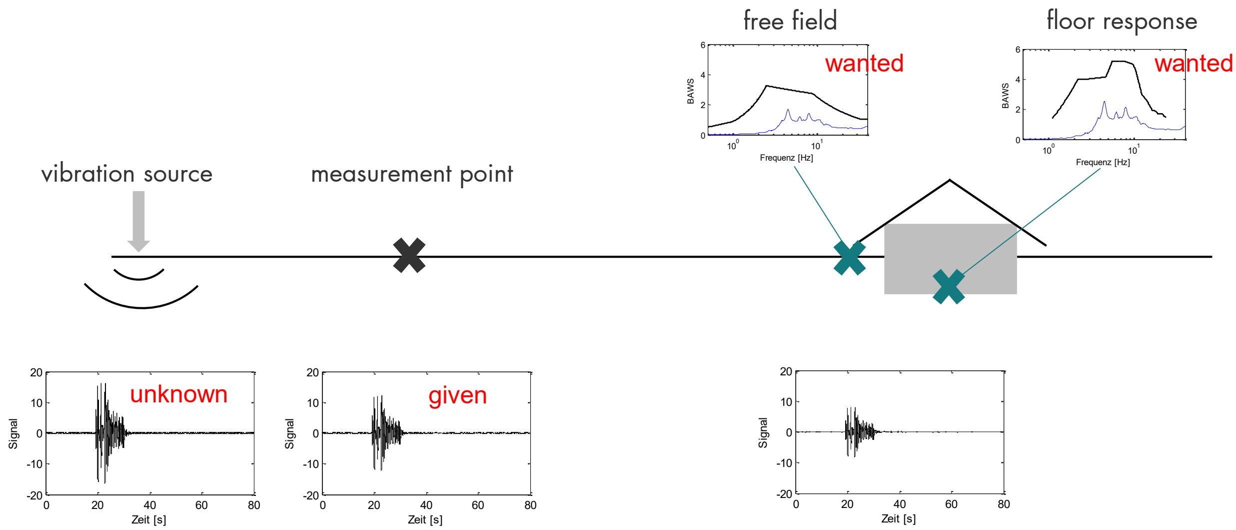

Figure 5. Vibration prognosis of vibration spectra.

DETAILED ENGINEERING

The detailed engineering includes the determination of the amount of explosives and the layout of boreholes as well as the design of protection measure against flying debris. In preparation for blasting, vertical and transverse slits are driven and blastholes are created in the blast areas for the blasting charges. After placing and stemming the blasting agent, the blast areas are covered in order to minimize scatter (primary flying debris protective measure). Depending on the requirements in the surrounding area, wire mesh and nonwoven material or heavy blast protection mats made of used tires can be used for this purpose. Scatter during impact cannot be influenced, so that secondary protection devices may need to be provided. For this purpose, fleece panels on scaffoldings positioned in front of objects worth of protection may be used. For detailed information see (Rapps et al, 2022).

PRESERVATION OF EVIDENCE

In the last step, the design engineer carries out different types of preservation of evidence. For buildings, where the predicted vibration velocities are higher than the applicable reference values according to DIN 4150-3, a visual preservation of evidence should be performed before and after the blasting. Furthermore, vibration measurements on these buildings as well as on critical structures and components are recommended. Free field measurement point are added, if the prediction and assessment of vibrations is carried out based on free field spectra. For additional information see (Feulner et al, 2022).

CONCLUSION

A systematic planning of experienced engineers leads to safe demolition by blasting. This includes the choose of blast strategy, verifications of collapse safety and structural safety of the pre-weakening structure, vibration prognosis and assessment, design of explosive charges and protective measure and preservation of evidence. With these steps, the economic and environmental related advantages of blasting demolition can also be applied for the number of cooling towers in the conventional and nuclear sector, which are or will be decommissioned in Germany in the next years.

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