5. Demolition blasting

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Analysis of air blast overpressures within a negative pressure boundary

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ABSTRACT: Harmonic energetic delamination of a T2 building is being considered for demolition at a formerly known atomic lab. The T2 building is within a containment structure that is under a negative pressure of -49 Pa (-0.2 inches of WC) so that no remaining radioactive material is leaked out. The T2 containment enclosure is a portal frame-type system that spans east/west over 35.05 m (114'-11 7/8") and spaced 2.9 m (9'-6") apart. The west side of the portal frames is supported by a 64 cm (2'-1") thick concrete wall which is backfilled to the west and open to the T2 basement to the east. The east side of the portal frames is supported by a 61 cm (2'-0") thick concrete wall that is backfilled to the east and open to the tank farm vaults to the west. A concrete slab-type footing supports both the east and west walls. Transverse walls provide lateral support for the walls as part of the original design. The west wall has an elevated slab that provides further stiffening of the concrete wall between the transverse walls. Previously, delamination had been considered for the neighbouring S2 building, but plans to do so were aborted. During the review period for S2 several issues were brought up by authorities, most notably Air Overpressure (AOP). Most typical demolition projects using blasting methods are performed in open air, under atmospheric pressure. Using these methods within the containment enclosure led to failure to prove success to the level of certainty authorities were expecting. At T2, the AOP concern also exists, although there are portions of T2 that are more favourable to gaining client's approval. Unfortunately, the most challenging of the T2 delamination involves a 2.4 m (8') concrete wall. This challenge is founded on the fact that it is approximately 7.6 m (25') from the containment boundary. A preliminary calculation suggests that AOP at this distance will exceed the operational pressure transient that the containment is designed to absorb. The production of expansive gases during detonation events produces increases in the base air pressure values due to compression of the existing volume of air within the facilities. Effects of this phenomenon are not generally considered in open air AOP estimates and were considered in the demolition of the T2 building given that delamination activities involving detonation of explosives will take place within a fixed volume, within the negative pressure containment. A theory was proposed to phase the demolition such that the blast burden and AOP relieves to the pipe tunnel side. In addition, a sound pressure wave survey was conducted inside the T2 building to estimate site specific attenuation curves under negative pressure. These results were used to develop site specific attenuation curves that led to a blast design that ensured pressure levels would not exceed the allowable 49 Pa (0.2 inches of WC) at the containment boundary, making demolition of the T2 building by explosives possible.

1 AIR BLAST OVERPRESSURES

Air overpressures (AOP) can be simply defined as additional pressure generated from a blast above normal atmospheric pressure. Air vibrations are time-histories of these air overpressures. AOPs travel at the speed of sound. Hence, at sea level, the velocity of sound in air is approximately 335 m/sec (1,100 ft/sec) at 7°C (45°F) with no wind. As the temperature and wind velocity increase, the sonic velocity increases. Therefore, the sonic velocity affects the arrival time of air overpressures.

AOPs are pressure waves that create a compression or positive pressure (push) followed by a dilatation or negative pressure (pull) effect. The amplitudes are measured in pascals (Pa), millibars (mb) or pounds/inch^2 (psi) above the ambient pressure. The pressures are reported as time histories. Air blast overpressures may also be reported as the sound equivalent in decibels (dB) and are calculated from measured pressures by Equation 1:

$$P_s = 20 \times \log\left(\frac{P}{P_o}\right) \qquad (1)$$

Where: Ps = pressure level, dB (psi); P = measured pressure, pascals (psi); Po = reference pressure, typically 2×10^{-9} (psi)

The methodology to estimate air blast overpressures and ground vibration is similar. Both present the same limitations. AOP is plotted against the cube root scale distance using a log-log graph and the AOP is determined by statistical methods as in ground vibration. Since air blast is measured in decibels, pressures can be plotted in a log-log scale graph versus cube-root scaled distance and the AOP can be monitored to determine full waveform as with ground vibrations. The cube root scaled distance SD^3 is used to evaluate air pressure attenuation using Equation 2:

$$SD_3 = R/W^{1/3} \qquad (2)$$

The best fit line to estimate the AOP from scaled distance, as defined for ground vibration, is determined by Equation 3:

$$P = A\,(SD)^{-B} \qquad (3)$$

Where: P = air overpressure, dB (psi); SD3 = cube root scaled distance, m/kg 1/3 (ft/lb$^{1/3}$); A = site constant (intercept of line at SD_3 value of 1); B = slope of the line (note that the slope is negative)

Typical AOP data from similar operations were

Table 1. Air overpressure from open air operations at normal atmospheric pressure.

Air Over-pressure (psf)	Air Over-pressure (in H_2O)	Air Over-pressure (dB)	Air Over-pressure (psi)	Intercept of the line at a SD_3 Value of 1 (A)	Slope of the Line (B)	Distance from Blast to Monitor Point (Feet) (R)	Charge Weight (lbs) (W)	SD (SD_3)
5988.56	1152.28	203.13	41.58723	19.57	-1.122	1	7.5	0.511
1375.74	264.71	190.36	9.55376	9.79	-1.122	2	7.5	1.022
581.93	111.97	182.88	4.04118	6.52	-1.122	3	7.5	1.533
316.05	60.81	177.58	2.19477	4.89	-1.122	4	7.5	2.043
196.84	37.87	173.47	1.36693	3.91	-1.122	5	7.5	2.554
133.69	25.72	170.11	0.92837	3.26	-1.122	6	7.5	3.065
96.39	18.55	167.27	0.66936	2.8	-1.122	7	7.5	3.576
72.6	13.97	164.8	0.5042	2.45	-1.122	8	7.5	4.087
56.55	10.88	162.63	0.3927	2.17	-1.122	9	7.5	4.598
46.87	9.02	161	0.32549	1.96	-1.1	10	7.5	5.109
11.17	2.15	148.55	0.07758	1	-1.1	20	7.5	10.217
7.15	1.38	144.67	0.04966	1	-1.1	30	7.5	15.326
5.21	1	141.92	0.03619	1	-1.1	40	7.5	20.435
4.08	0.78	139.79	0.02831	1	-1.1	50	7.5	25.544
3.34	0.64	138.05	0.02317	1	-1.1	60	7.5	30.652
2.82	0.54	136.58	0.01955	1	-1.1	70	7.5	35.761
2.43	0.47	135.3	0.01688	1	-1.1	80	7.5	40.87
2.14	0.41	134.18	0.01483	1	-1.1	90	7.5	45.979
1.9	0.37	133.17	0.01321	1	-1.1	100	7.5	51.087

obtained from the demolition contractor. The data corresponds to open air operations for an initial charge load of 7.5 lbs. The data results are shown in Table 1.

The interpreted attenuation curve representing the data from Table 1 in units of decibels is described by Equation 4 and plotted in Figure 1.

$AOP = 191\ SD^{-.090}(dB)$ *with a 95% level of confidence* (4)

$AOP = 327\ SD^{-1.45}$ *(in H_2O) with a 95% level of confidence* (5)

2 FORMER ATOMIC POWER LABORATORY DEMOLITION CASE STUDY

A theory was proposed to phase the demolition of an 8-foot structural wall to expediate completion of the project demolition. The engineering group has proposed the use of harmonic delamination as the primary excavation method of the wall, allowing for a faster completion of the final stages of the overall demolition given that time constraints of the project. The harmonic delamination plan consists of making sure the blast burden and AOP relieves to the pipe tunnel side, so that air overpressures are redirected to the larger volume area, therefore decaying in strength as they approach the enclosure. The challenge was the unknown rate of decay that AOPs would experience given that the inside enclosure is under the negative pressure, as opposed to atmospheric pressure, and the pressure the AOP exert on the enclosure boundary. Several methods for estimating pressure decays were researched, and little to none were found that would estimate how the AOP waves would decay when subjected to a pressure other than the atmospheric pressure. It

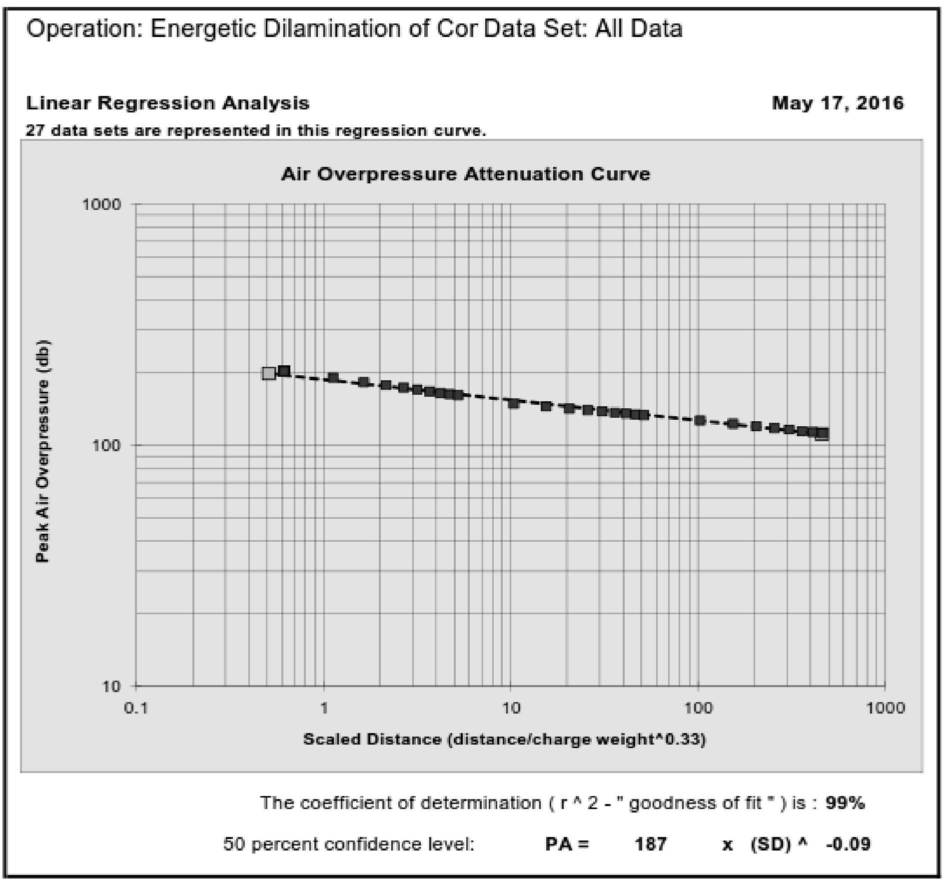

Figure 1. AOP attenuation curve - open air.

was determined that the AOP cannot be estimated by AOP attenuation curves given that the known AOP attenuation curves as those would only apply to blasts conducted in the open, under atmospheric pressure, which was not the case for the referent case study. Therefore, the team worked developing a site-specific plan to measure AOPs, and modelled AOPs as sounds pressures since these would best describe the transient pressure under negative pressure. It was known that AOP propagate through the atmosphere like compression waves (p-waves) on the ground. It was also known that no shear waves (S waves) exist in the atmosphere, since air has no shear strength.

The plan layout (Figure 2) included the following steps:

– A sound wave survey was conducted inside the T2 building to estimate site specific sound wave attenuation curves within the enclosure.
– The allowable pressure was determined as the pressure ‘just’ smaller than the magnitude of the ventilation fan head pressure, i.e. +44 Pa (+0.18 inches of WC), so that a pressure differential would be just below zero at the containment boundary in order to maintain the pressure draft. This pressure in units of dB is equivalent to 127 dB.
– Measurements were taken at three locations: vault monitor EHK030033 (17.25’ from the source), monitor EHK090091 (31.75’ from the source), and the pipe tunnel west wall monitor (52’ for the source).

The source of the sound pressure was Skidsteer Hydraulic Hammer and measurements were recorded during a two-shift day period. The monitoring equipment include 3M Edge q4 dosimeter set as Fast Response C- weighted scale.

3 EFFECT OF DEMOLITION ACTIVITIES ON THE CONTAINMENT ENCLOSURE

The current configuration of the T2 building consists of levels 322 and below (Figure 3) enclosed on a containment structure that was placed to avoid leakage of radioactive material to the environment. During demolition activities, maintaining the strength and preventing the addition of load to the east and west walls supporting the portal frame are necessary for the continued integrity of the containment enclosure. The wall supporting the east side of the portal frame was maintained in its current configuration and no loads were added. Upon completion of decontamination activities, and removal of the containment enclosure, the vaults were removed.

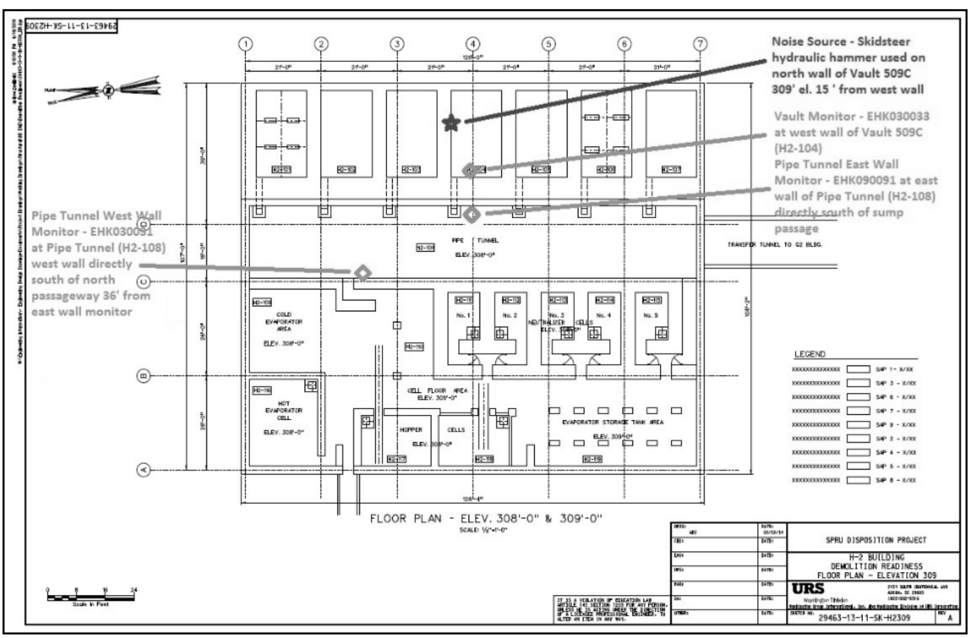

Figure 2. Sound wave survey monitor locations.

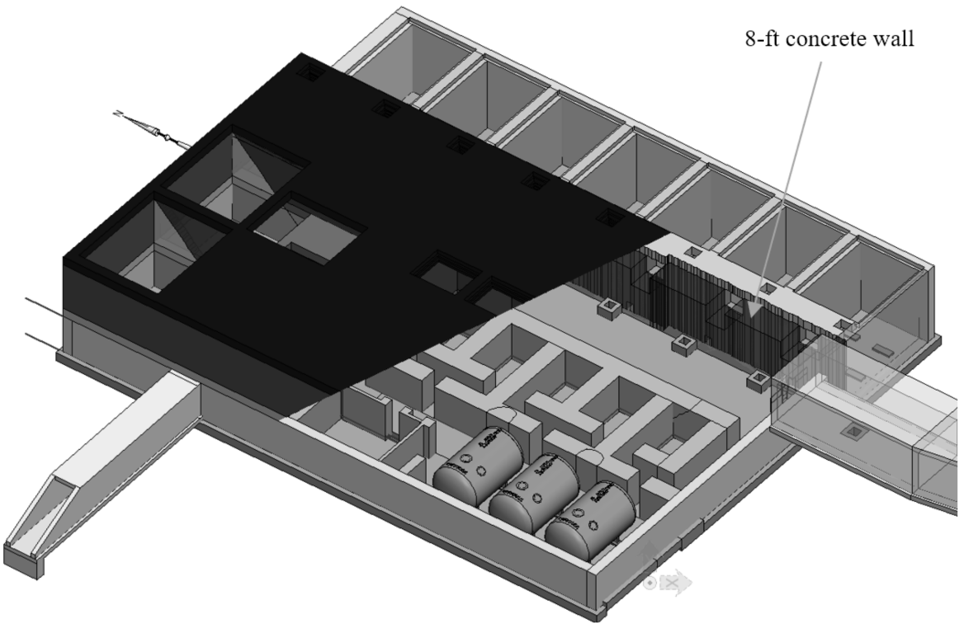

Figure 3. T2 building configuration.

Decontamination efforts will have a *de minimis* effect on the wall strength.

4 S2/T2 TUNNEL

The S2/T2 tunnel connects the S2 and T2 buildings for the purpose of conveyance of material and personnel. No process equipment was housed in the tunnel. The tunnel structure consists of reinforced concrete and, except for a small portion near S2, is buried below grade. A ventilation partition was erected approximately midway along the tunnel as part of the operation. Prior to open air demolition of T2, the portion of the tunnel south of the partition was off limits to personnel due to industrial hazards. Open air demolition activities at S2 will not affect the north

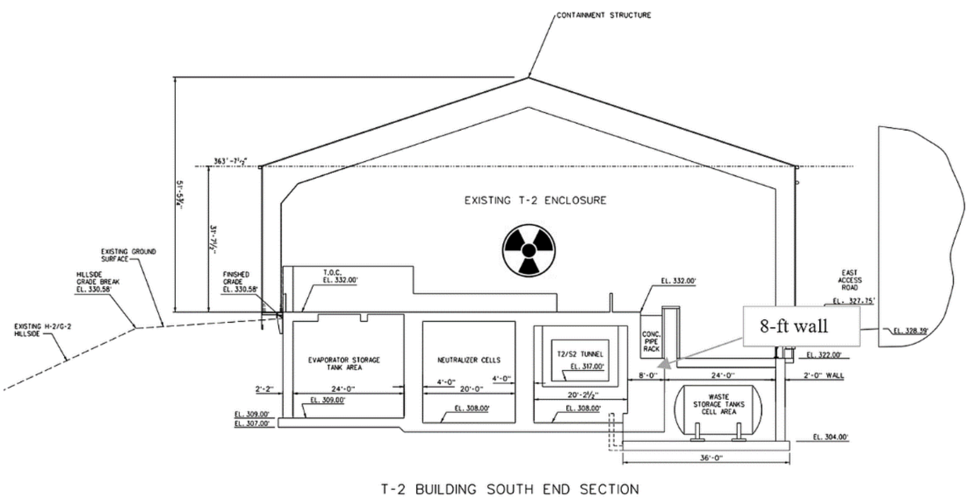

Figure 4. T2 building, typical section,

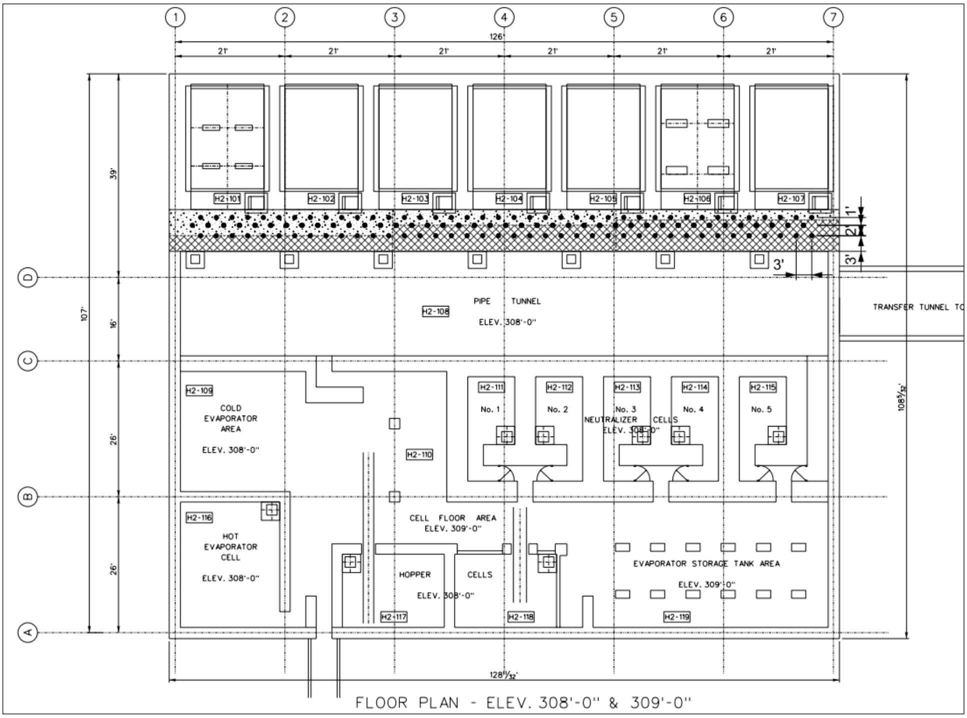

Figure 5. Proposed drilling plan for demolition of 8' wall.

portion of the tunnel. Should personnel access south of the partition become necessary after open demolition commences, it may be done with adequate planning (i.e., suspend heavy equipment activities and inspect for collateral damage).

5 DEMOLITION OF 2.4 M (8-FT) WALL

The 2.4 m (8 ft) wall extends from north to south 38.4 m (126 ft) in length and is enclosed by the 304 and 322 level slabs. Demolition of this wall presents some challenges. However, the structural enclosure can be used to our advantage.

6 DELAMINATION STAGING PLAN

To manage the air blast overpressures (AOPs) generated by the blast, the charge was placed in a way such that the blast wave could be skewed (Figure 4). The explosives were placed away from the containment boundary side of the wall such that the burden and AOP were on the pipe tunnel side. For instance, drilling holes and placing explosives so that they are 91 cm (3 ft) from the

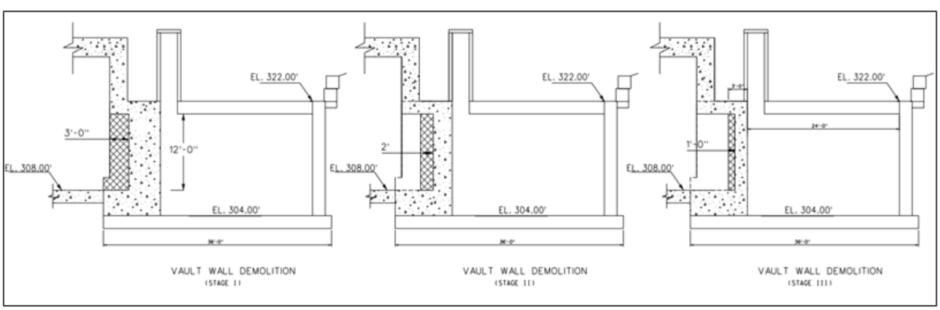

Figure 6. 8-ft Wall demolition staging section.

pipe tunnel side of the 2.4 m (8 ft) thick wall, leaving 1.5 m (5 ft) from the vault side of the wall (containment boundary ~7.6 m (25 ft) from the vault side of the 2.4 m (8 ft) wall), leaving a 1.5 m (5 ft) thick wall and 91 cm (3 ft) of fractured material on the pipe tunnel side (Figure 5 and Figure 6). Then the next phase of delamination would leave 91 cm (3 ft) of wall on the vault side and 60 cm (2 ft) of fractured material on the pipe tunnel side, then 30 cm (1 ft) of fractured material on the pipe tunnel side and 91 cm (2 ft) on the vault side. Beyond that demolition by mechanical means would start.

7 GAS NUISANCE

At this point, the AOP generated by the detonation of the charge is unknown. The production of expansive gases during detonation events increases the base air pressure values due to compression of the existing volume of air within facilities. Channelling or funnelling of these gases through existing corridors, conduits and slab openings may focus these rapid pressure rises in localised areas of the structure. Effects of this phenomenon are not generally considered in open air AOP estimates and were considered in the demolition of the T2 building given that delamination activities involving detonation of explosives will take place within a fixed volume, under a negative pressure.

7.1 Pressures Due to Expanding Gases

Based on the specifics of the explosive product, the gas volume produced by a single detonation is 32 mol/kg of explosive. The dimensions of the tunnel are 35 m x 6.1 m x 6.7 m (115' x 20' x 22') with a volume of approximately 1,430 m^3 (51,000 ft^3), and an equivalent radius of 7 m (23 ft).

Using the ideal gas equation PV= nRT, assuming 1 charge load of 3.4 kg (7.5 lbs) per delay, the explosion will generate approximately 155 Pa (3.24 psf) of pressure within the pipe tunnel due to the expanding gases. The target is to maintain a pressure no greater than 49 Pa (0.2 inches of WC) or (1.03 psf) at the containment boundary.

8 ASSUMPTIONS

- AOPs behave as ideal gas
- The process of expansion of explosive gases is adiabatic

Given the following:

Ideal Gas: PV=nRT

Volume of Enclosure:

$V_E := 19821 m^3$ (700,000 ft^3)

Explosive Load: $W := 3kg$ (7 lb)

Dynamax Pro: $n := 32 \dfrac{mol}{kg}$

$G_{release} := n \cdot W = 96.00\, mol$

Gas Constant: $R := 8.31 kg \cdot \dfrac{m^2}{sec^2 mol \cdot K}$

Temperature: $T := 278K$

Tunnel Vol.: V_T = 1,430 m3 (51,000 ft3)

$Pressure := n \cdot W \cdot R \cdot \dfrac{T}{V_T} = 155.09\, Pa$ (3.2 psf)

Volume at P atm: $G_{release} \cdot R \cdot \dfrac{T}{101300Pa} = 2.19\, m^3$

$Pressure_E := n \cdot W \cdot R \cdot \dfrac{T}{V_E} = 11.19 \cdot Pa$ (0.24 psf)

Ventilation Rate: $Q := 32000cfm$

Equiv. Radius: $r := \sqrt[3]{3 \cdot \dfrac{V_T}{4 \cdot \pi}} = 6.99 \cdot m$ (25 ft)

Time to Exhaust: $Time := \dfrac{G_{release} \cdot R \cdot \dfrac{T}{101300Pa}}{Q} = 0.14\, s$

As shown above, the pressure within the pipe tunnel due to the expansion of gases was 155 Pa (3.43 psf) at the equivalent radius. When the expanding gases encounter the open volume of the enclosure (tunnel/enclosure), the volume increases significantly (from 51,000 ft^3 to ~700,000 ft^3). Based on this volume increase, the pressure decreased from **155 Pa (3.2) psf to 11.2 Pa (0.24 psf)**. In addition, it is expected that the ventilation system will take approximately 0.14 sec (or 140 milliseconds) to dissipate the expanding gases from the explosive detonation.

9 PRESSURES DUE TO DETONATION OF EXPLOSIVES USING AOP EQUATION

Based on the specifics of the explosive product and using the AOP attenuation curve obtained from similar open-air operations (Figure 7), the AOP generated by the detonation of the charge would be in the order of 8.5 in H_2O, which will significantly exceed the allowable 0.2 in H2O.

AOP = 327 SD-1.45 (in H2O) = 8.5 in H_2O

However, the fact that the attenuation curve is expected to be different when under negative pressure, this estimate was ruled out.

10 SOUND PRESSURE SURVEY RESULTS

To estimate the unknown AOP attenuation curves for transient pressures under the negative pressure,

Density	(g/cc) Avg	1.45
Energy[a]	(cal/g)	1,055
	(cal/cc)	1,510
Relative Weight Strength[a]		1.20
Relative Bulk Strength[a,b]		2.10
Velocity[c]	(m/s)	6,000
	(ft/s)	19,700
Detonation Pressure[c]	(Kbars)	130
Gas Volume[a]	(moles/kg)	32
Water Resistance		Excellent
Fume Class[d]		IME1

[a] All Dyno Nobel Inc. energy and gas volume values are calculated using PRODET™ the computer code developed by Dyno Nobel Inc. for its exclusive use. Other computer codes may give different values.
[b] ANFO = 1.00 @ 0.82 g/cc
[c] Unconfined @ 50 mm (2 in) diameter.
[d] IME Fume Class 1 in convolute paper shell only. Not Fume Class 1 in paper tube shell. Natural Resources Canada Fume Class approvals pending.

Hazardous Shipping Description
Explosive, Blasting, Type A 1.1D UN 0081 II

Figure 7. Dyno Nobel Dynamax Pro specification.

the survey was conducted within the T2 building containment structure which was under the -49 Pa (-0.2 inches of WC or -1.03 psf) of pressure. Several recording stations were placed within the containment, and sound pressure at different distances, during several intervals were recorded. Sound pressures due to the hydraulic hammer wall scabbling operation in T2 vault area were recorded. Site limitations force the work to cease before 9:00 PM each day. The data between 6:00 pm and 8:30 pm segment presents the best source of comparison across the subject wall boundary (Figure 8). Consequently, an attenuation curve was developed, and the results were compared to attenuation curves obtained from open air operations.

The resulting attenuation curve within the containment of the T2 building was described by the following expression (Equation 5), and results were plotted in logarithmic scale:

$$P = 184.73\ SD^{-0.213} \qquad (5)$$

When comparing attenuation curves obtained from conventional open air operations and the attenuation curves within the T2 containment (Figure 9), it is clear from the figure the slope of the AOP (inside T2) curve is about 2.5 times

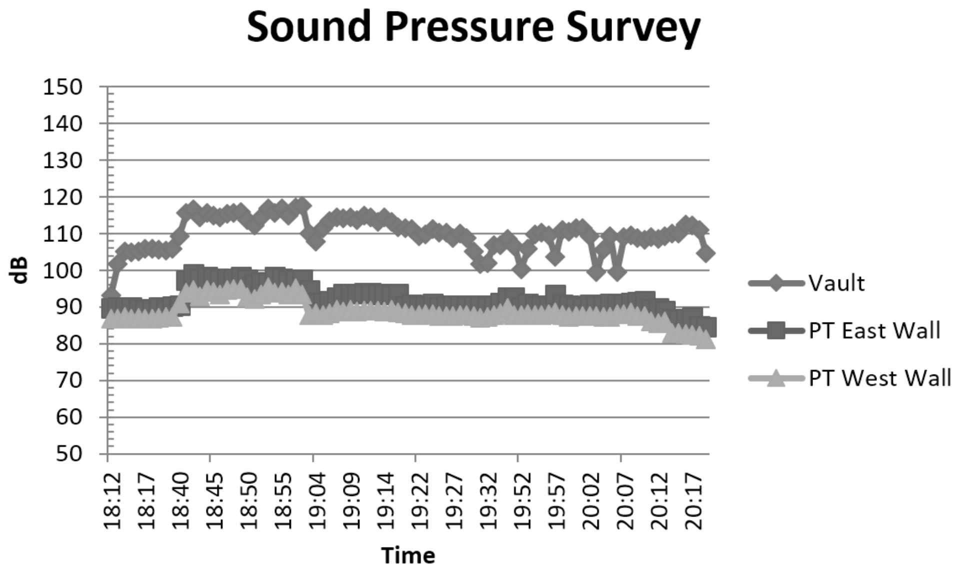

Figure 8. Sound pressure survey within T2 Building @ -49 Pa (-0.2 inches of WC).

steeper than that of the AOP (open air) given that the slope in the exponential equation is negative, and that the ratio is 1.81 (0.21/.084), the higher (negative) the faster the dissipation. This result makes sense as one would expect that the ventilation system would 'accelerate' the transient pressure dissipation. Consequently, one could conclude that the transient pressure attenuation would vent out faster. The question still is, what would the pressure be when the air blast wave reaches the boundary? (@ 25 ft from the blast). To answer this question, the attenuation curve developed using the results obtained from the sound wave survey (equation 5) was the basis to estimate the approximate transient pressure at a given scale distance.

11 DISCUSSION

At this point, an estimate of attenuation curves for open air operations, attenuation of sound pressure within the containment, and pressures due to

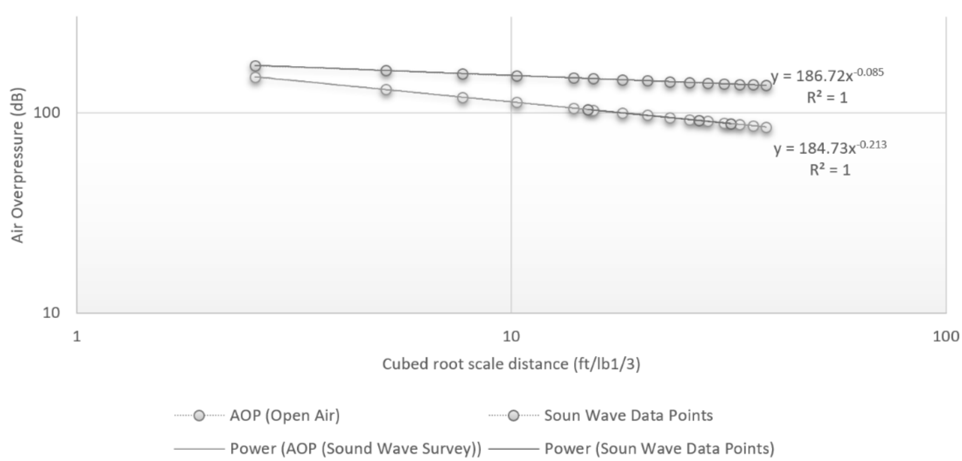

Figure 9. AOP attenuation curve comparison.

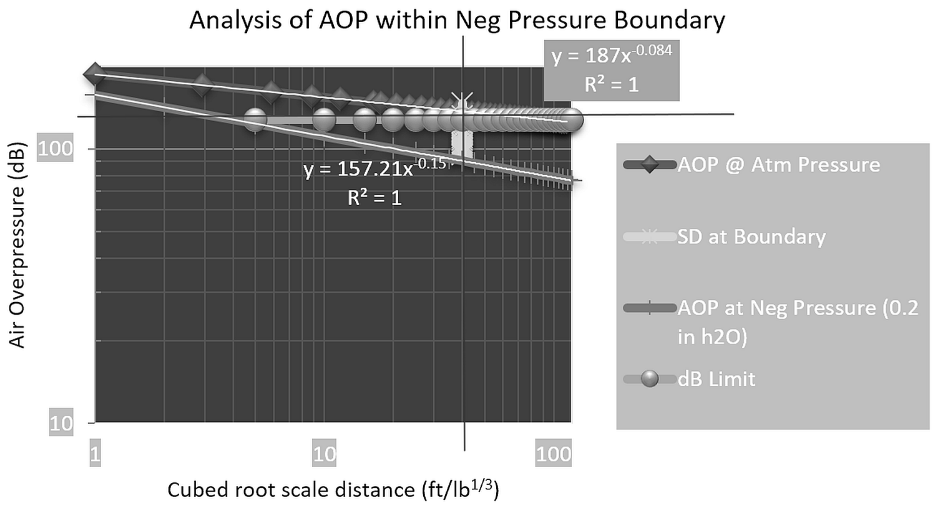

Figure 10. Comparison of AOPs at different conditions.

explosive's expanding gases have been calculated. As previously mentioned, the goal was to maintain a pressure no greater than 49 Pa (1.03 psf) at an equivalent SD of 41 ft/lb 0.33. In terms of dB, this pressure was equivalent to 128 dB (Figure 10). It was clear from Figure 10 that the allowable pressure of 128 dB would be exceeded when the AOP wave reaches the boundary if the open-air attenuation curve was used. However, it was determined from the sound wave survey that the AOP pressure would fall well below the allowable pressure at the same scale distance given that the sound wave attenuation curve has a much 'steeper' slope. Therefore, one can conclude that AOP within the negative would decay much faster than in open air, and that the pressure level at the boundary would be far below the target. The attenuation curve (equation 5) was then used to develop a blast design.

Note: It is worth noting that the rate of decay is independent of the charge load. For instance: A charge load of 5 lb, 7 lb, or any other charge load would decay at the same rate given that the decay rate is described by the negative component of the equation (slope).

12 BLAST DESIGN

Based on the findings of this analysis, a blast design was developed for the demolition of the 8-ft wall following specifications included in the ISEE Blasters' Handbook, 18th Edition.

Given the following:

$d := 2\ \text{in}$

$SG_{ex} := 1.45$

$\gamma_{conc} := 150\ \frac{\text{lb}}{\text{ft}^3}$

$$k := \left[\left[30\cdot\left(\frac{SG_{ex}}{1.4}\right)^{.33}\cdot\left(\frac{160}{\gamma_{conc}}\right)^{.33}\right]\right] = 31.00$$

(Ash's Equation)

Burden, $B := k\cdot d = 5.17\cdot\text{ft}$

Spacing, $S := B = 5.17\cdot\text{ft}$

Stemming, $S_t := 2\cdot d = 4.00\ \text{ft}$

Wall Height, $W_H := 14\ \text{ft}$

Hole height, $H := W_H - 2 = 12.00\ \text{ft}$

Column Height, $C := H - S_t = 8.00\ \text{ft}$

Length of the building floor $L := 126\ \text{ft}$

No. of Holes Required: $\frac{L}{S} = 24.38$

Explosive Load per hole:

$W' := 0.341\cdot SG_{ex}\cdot d^2\cdot C = 15.82\ \text{lbs}$

$$P_F := \frac{W'}{B'\cdot S'\cdot H\cdot\frac{\gamma_{conc}}{2000}} = 1.17\ \frac{\text{lb}_{ex}}{\text{ton}}$$

13 BLAST PATTERN ADJUSTMENT

Given that the purpose of this operation was mainly to make the structure just fail in tension (not complete breakage) while maintaining the integrity of the enclosure, it was decided to decrease charge load from 7.2 kg (15.82 lbs) to 3.4 kg (7.5 lbs) and strategically placed the blast holes in a way that would allow skewing the shockwaves towards the pipe tunnel and away from the enclosure. As a result, the new blast design reduced the burden from 1.5 m (5 ft) to 0.91 m (3 ft) and the spacing to 0.91 m (3 ft). This reduction in the blast pattern resulted in an increase in the number of holes required from 24 to 42, and therefore, resulted in a higher powder factor.

13.1 New Blast Design:

$$B' := 3.00\,\mathrm{ft}$$

$$S' := B' = 3.00$$

$$W' := 7.5\,\mathrm{lb}$$

$$P_F := \frac{W'}{B' \cdot S' \cdot H \cdot \frac{\gamma_{conc}}{2000}} = 0.59 \quad \frac{\mathrm{lb_{ex}}}{\mathrm{ton}}$$

No of Holes $No := \frac{L}{S'} = 42.00$

14 CONCLUSIONS AND RECOMMENDATIONS

Based on the preceding analysis, measurement of air overpressures under negative pressure is challenging. However, the analysis suggests that harmonic energetic delamination of the 2.4 m (8 ft) wall within the enclosure was possible without compromising the integrity of the enclosure. The pressure levels were maintained below the target level of -49 Pa (-1.03 psf, or 128 dB). The maximum charge of 3.4 kg (7.5 lbs) was used. The charge was detonated in a scattered sequence so that there was enough time to vent out the gases. This delay time was in the order of 140 milliseconds given the rate of the ventilation system was 906 m^3/min (32,000 cfm). Since the volume of the containment was significantly larger than that of the tunnel, the pressure at the boundary dropped below the target value of 49 Pa (1.03 psf or 128 dB) at the arrival. The pressure at the boundary using the ideal gas equation was estimated as 12.7 Pa (0.26 psf) which was well below the target value of 49 Pa (1.03 psf).

It was concluded that attenuation curves from ‘open air’ cannot be used as reference when blasting under pressure conditions other than atmospheric pressure. This was confirmed by the sharp difference in rate of decays (slope) on both conditions. Detonation of low charge explosives within the containment of the building was therefore possible.

The use of electronic detonators is recommended to accurately achieve the required delay time between charge loads.

Disclaimer - The findings and conclusions in this paper are those of the author and do not necessarily represent the views of the government or private entities. Mention of company names and products does not constitute endorsement by the author.

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Demolition and reuse of a 152 m chimney at Amager Resource Center, Copenhagen

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ABSTRACT: An old incineration plant in Copenhagen, Denmark has previously been demolished and the last remaining structure to demolish was a 152 m tall concrete chimney. In the immediate vicinity of the chimney there was new incinerator plant and a powerplant providing both electricity and district heating. Due to the limited space the fall of the chimney had to be shortened. The considerations and process for tendering the chimney for blasting, getting permission from authorities, dialogue with neighbours and other stakeholders, selection of the demolition company, and the idea of recycling the concrete for new structures will be described. The environmental impact had a very high priority and comparisons on forecasts and measuring was recorded. The blast planning was done with the assistance of experts from Germany and differences in culture and traditions could be observed as a curiosity. The practical work was challenged by heavy wind up to the day before blasting. On Sunday 31st October 2021 in the morning the chimney was successfully blasted. The environmental impacts in the form of dust, noise, vibration, air overpressure and ejected fragments were monitored, and only negligible impacts were observed.

1 INTRODUCTION

On 31 October 2021 the 152 m tall chimney of the former Amagerforbrændingen waste incinerator plant in Copenhagen was successfully demolished. Amagerforbrændingen was built in 1970 to handle waste from the city of Copenhagen and parts of the suburbs.

The demolition was part of a plan to renew the waste management in Copenhagen. From 2014 to 2017 a new state of the art waste incineration plant ‘Amager Bakke’ was built north of the existing plant. From 2017 to 2020 the existing plant was demolished, leaving only the chimney. After the demolition of the chimney, a waste sorting plant is planned on the site.

Figure 1. Chimney and surrounding area. Chimney (1), new incineration plant (2), ammonia tanks (3), transformer building (4), powerplant (5), municipality workshops (6). Insert: Location near central Copenhagen.

The demolition was interesting for several reasons: Very few structures of this size have previously been demolished in Denmark, the chimney was located in an urban area with more than 1 million people living within view of the chimney, a number of important utility buildings and infrastructure were located in the immediate proximity and finally the reuse of the concrete for environmental reasons.

The demolition had not been announced by the media until the time of demolition. The main reason for this was to avoid the gathering of large crowds during the COVID-19 pandemic.

1.1 The chimney

The chimney consisted of a relatively thin reinforced concrete shell, 152.3 m tall from the

Figure 2. Left - the chimney, seen from north east before the demolition. The removal of outside paint is in progress. To the right side of the frame, the new incineration plant is visible. Right - Original drawing of the chimney showing the shape and intermediate decks among other things.

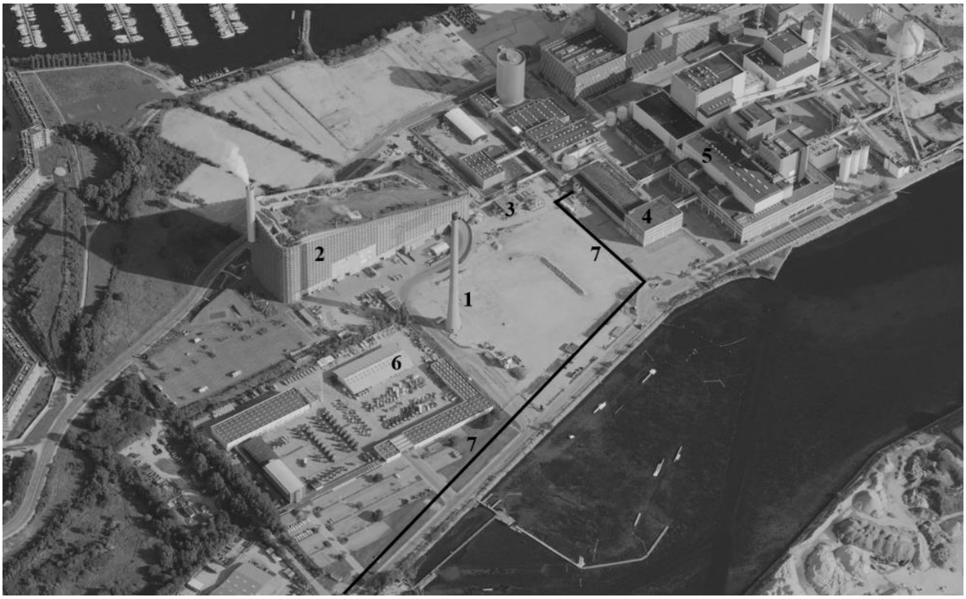

Figure 3. Area surrounding the chimney. The approximate location of the main power lines and main district heating pipes is denoted by the black line (7). Other numbers as per caption to Figure 1.

foundation to the top (148.7 m from ground level to the top).

The chimney's foundation was placed 3.6 m below ground level. From the foundation to a height of 51.4 m the chimney was shaped as a parabolic 'trumpet' and the top part was shaped like a frustum of a cone. At the base the chimney had a diameter of 14 m and at the top the diameter was 5.4 m. The thickness was 33 cm at the base, gradually decreasing to a constant thickness of 18 cm from a height of 73 m to the top.

Inside the chimney, intermediate floors were placed at 18 m, 58.7 m, 102.7 m and 144 m above ground.

The structure was reinforced using traditional reinforcement. A 7.9 m tall portal was placed at ground level on the eastern side. The estimated total mass of the concrete shell of the chimney was 2,100 metric tons.

The chimney was fitted with an internal rack and pinon elevator, an internal emergency ladder, aviation obstruction lights and guardrails at the top. Prior to the demolition, the smoke pipe had been removed and the external paint had been cleaned off.

1.2 The surroundings

Near the chimney, several other buildings and utilities were located within a range where they could potentially be affected, if the demolition would not go as planned.

To the north, the new incinerator plant was located about 105 m from the chimney (2). 150 m to the northeast was a storage facility for ammonia (3). The nearest building to the northeast, at a distance of 200 m, contained transformers supplying electricity to Copenhagen (4) and further northeast was the power plant Amagerværket (5) at 280 m. A large tank farm area was located 450 m to the east (outside the figure). Along the road to the south were the main cables supplying electricity and district heating to Copenhagen (7). And 45 m to the south and west were buildings used by the Copenhagen Municipality for technical operations and maintenance (6).

Any damage to any of the named neighbouring facilities had the potential to severely disrupt the supply of services to the city of Copenhagen.

2 ORGANISATION

I/S Amager Resource Center (ARC) hired the engineering consultancy NIRAS A/S (NIRAS) to conduct preliminary studies of the demolition of the chimney. The preliminary studies showed that the demolition of the chimney using explosives was feasible and NIRAS was asked to draft tender materials and assist during the tendering process,

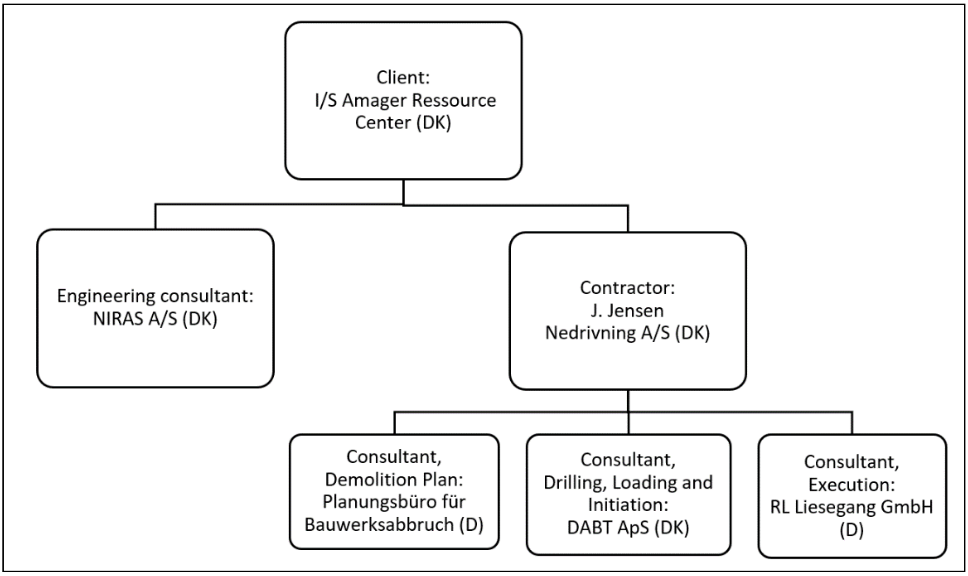

Figure 4. Organisation diagram of the demolition project.

and to conduct construction management and supervision during the execution.

Three bids were received and the bid from J. Jensen Nedrivning A/S (J. Jensen) was accepted. One of the requirements in the tender material was that the contractor should have international experience from the demolition of similar structures. Therefore J. Jensen hired Dr. Ing. Rainer Melzer from Planungsbüro für Bauwerksabbruch in Dresden, Germany to help draft the demolition plan and Michael Schneider from RL Liesegang GmbH in Cologne, Germany to provide quality assurance of the execution. Furthermore, the Danish company DABT ApS was hired to design actual blasts and draft the drilling, charging and initiation plans.

3 COMMUNICATION WITH AUTHORITIES, NEIGHBOURS AND OTHER STAKEHOLDERS

One of the reasons the demolition project was successfully completed, was due to the early involvement and good and positive dialogue with the authorities and neighbours.

The authorities included the Copenhagen Municipality, the Danish National Police, the Copenhagen Police, and the Greater Copenhagen Fire and Rescue Service.

Regular meetings were held from approximately 6 months prior to the demolition, before the tendering process was initiated. The meetings gave the authorities advance notice that the project was underway, enabling any questions and requirements to be handled early and included in the tender material to ensure that the contractors application for permission to use explosives would be quickly accepted. During the planning phase, a joint inspection visit was conducted with participants from the police and fire and rescue service.

In parallel with the meetings with the authorities, meetings were also held with neighbours. The meetings gave ARC the opportunity to explain exactly what was being planned and the neighbours were able to voice their concerns so any arising issues could be handled.

Because the neighbours mainly consisted of utility installations, any damage to neighbours could potentially provide significant disruption to the services provided to the city of Copenhagen. The dialogue with the neighbours therefore provided important input to the amount of protection measures implemented.

4 DEMOLITION PLAN

4.1 General method

In the preliminary studies carried out by NIRAS five possible methods for the demolition were identified. The first method was the traditional method for demolition of tall structures, where the

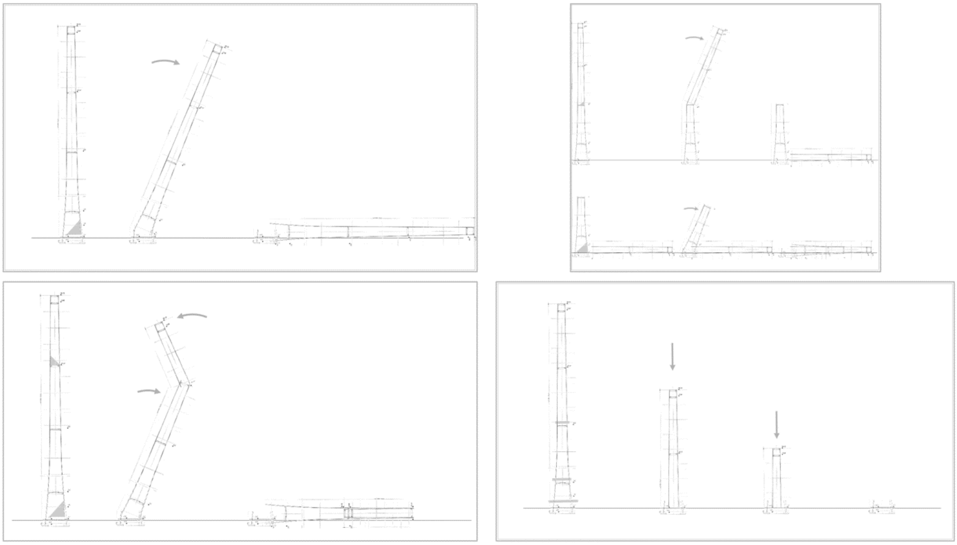

Figure 5. Possible demolition methods. Single cut (top left), two successive cuts (top right), zigzag (bottom left) and vertical implosion (bottom right).

chimney is demolished using a single cut at the bottom, causing it to fall in a single piece in all its length. To avoid hitting any nearby buildings or utilities, the direction of demolition should be in a north-easterly direction.

In the second method, the chimney would be demolished in two stages, first the top half, and then the lower half a few days later. Both parts

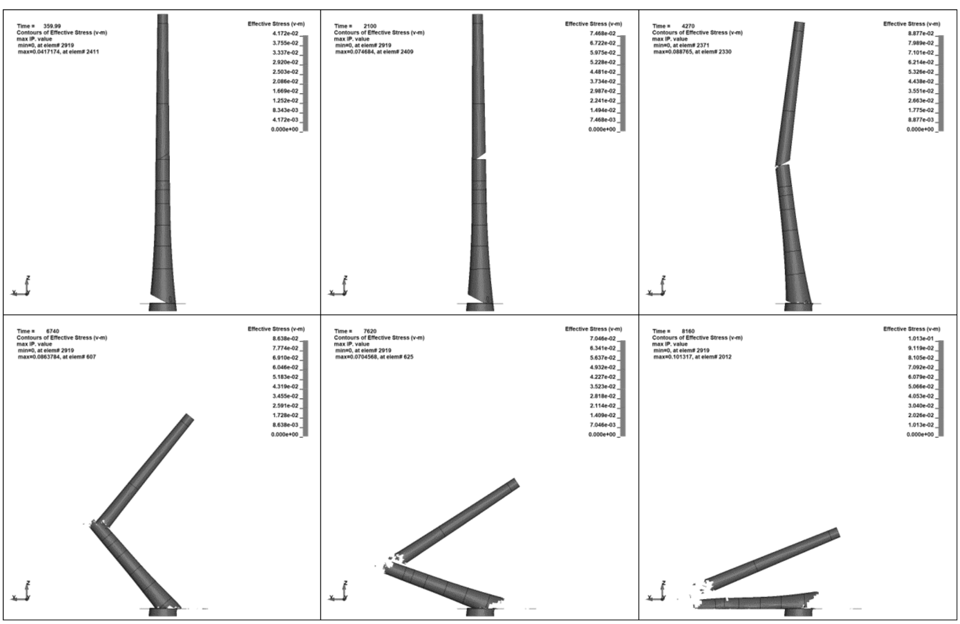

Figure 6. Dynamic simulation of the collapse mechanism made during the tender phase with the upper cut in 75 m height and a delay of 2 seconds before initiation of the upper section. In the end, the height of the upper section was raised to 90 m and the delay before initiation of the upper section was increased to 3 seconds.

would fall in a north-easterly direction.

This method would reduce the size of the impact area, but also introduce the requirement for some more complicated assessments about the stability of the lower part.

The third method would again see the chimney demolished in two parts, but with the two cuts facing in opposite directions and taking place at the same time, causing the chimney to collapse in a zigzag shaped manner. This method would also reduce the impact area, but in case of a misfire in one of the cuts, a large portion of the chimney could potentially fall outside the planned impact area.

The fourth method was a vertical implosion of the chimney, where the chimney would be crushed under its own weight. This method had the smallest impact area, but if the concrete strength was unevenly distributed, a part of the chimney could potentially fall in an uncontrolled direction.

The fifth method was mechanical demolition from the top using a movable platform and a small excavator.

A risk analysis of the different methods was performed, and the third method (zigzag) was recommended.

A dynamic finite element simulation of the collapse was carried out to confirm that the method would work and to help decide how the demolition should take place. Based on a series of dynamical simulations, it was in the end decided to raise the location of the upper cut and introduce a delay before initiating the upper cut, to ensure that the top of the chimney would not end up too far to the southwest.

4.2 Demolition plan

A demolition plan was made by Planungsbüro für Bauwerksabbruch by Dr.-Ing. Rainer Melzer who has a long reference list and great knowledge within this field.

A requirement was that the top of the chimney must not land too far behind the chimney as this would cause a problem for trucks who shall pass on the road behind the chimney. The upper cut was placed 90 m above ground level.

The specifications of the concrete from the drawings showed $\sigma_{min} \approx 27$ MN/m². Tests showed 44.5 MN/m² and the concrete was in excellent condition and much better than expected.

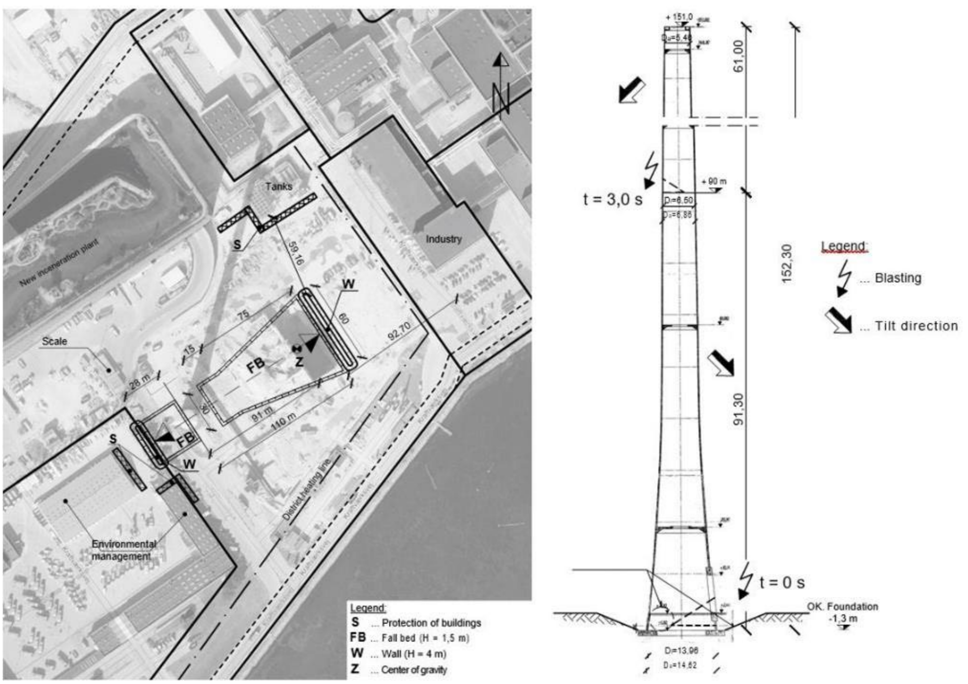

Figure 7. Plan of the area where the chimney is expected to land, including some protection measures. The sand cushion in the impact area was later changed to a series of trenches and berms (left) and demolition plan showing the location of the blasted sections (right).

Based on the demolition plan the blasting was approved and detailed planning could start.

4.3 Blast plan

4.3.1 Blasting of the bottom section

A plan for drilling, charging and firing of the lower cut was made.

A test blast on the chimney verified the calculations and the planned principle for the covering.

A substantial number of holes were to be drilled, and a hydraulic drilling machine was used. Drill holes Ø 38 mm were drilled in a 0.35 x 0.35 m pattern with a hole depth of 25 cm. In total 464 holes was made in the lower cut.

A specific charge of L_{spec} ~1 kg/m³ was chosen and test blasting documented that this was OK. Eurodyn 2000 Ø 25 mm was selected as the blasting agent and clay was used for stemming.

It was specified that a redundant firing system should be used. This meant that 464 detonators were to be used in each side of the chimney and

Figure 8. Initiation system on the northern side of the lower section. Two EXEL MS detonators are used in each hole, one ignited by a detonation-cord placed above and one ignited by a detonation cord placed below.

they would all be ignited independent of each other.

As charging would take days to be done it was decided to go for EXEL MS detonators.

EXEL MS step 1-20 was used and was ignited by a detonating cord 5.3 g/m.

The charging was completed without any problems, but it took time to keep everything nice and easy to overview.

4.3.2 Blasting of the upper section

Thickness of the chimney at the upper section was 18 cm.

The plan from Dr.-Ing. Rainer Melzer indicated that a small pre-weakening in each side would be sufficient to form the hinge. The concrete in between would be drilled and blasted.

As the concrete was very hard and drilling was difficult, it was decided to increase the pre-weakening in each side and to pre-weaken the front as well.

New calculations were done by Niras which showed that the top of the chimney would not become unstable and the windspeed could be storm or even hurricane without becoming a risk.

Due to the very small thickness of the concrete, the drill holes were drilled at a 45° angle and the drill pattern was intensified to 0.25 x 0.25 m. It was decided to use NSP711, a PETN based plastic explosive approximately 20% stronger than Eurodyn 2000. The specific charge was increased to 2 kg/m³ as the stemming would be very short. Redundant ignition was a requirement.

The number of holes was reduced to in total 106 holes.

Because the upper cut was 90 m up in the air, and because buildings were located approximately 45 m behind the chimney, heavy covering was required. The covering consisted of a layer of geotextile fabric, a layer of chain link fence, a layer of overlapping heavy blasting mats and finally a second layer of geotextile fabric. Geotextile fabric and chain link fence was brought all the way around the structure, to catch any debris from the breaking of the concrete on the rear face of the chimney.

5 EXECUTION

The work at the chimney was carried out by a small but effective team. The tools used were mainly handheld power tools for cutting and drilling, excavators for digging and low-level lifting and mobile cranes for high level lifting of both materials and a basket as work platform. A drill rig was used to drill the boreholes for the lower cut.

5.1 Challenges

The pre-weakening, drilling, charging, and covering 90 m above the ground showed to be much more challenging as everything was supposed to be done by hand and working from a free hanging basket as this was the only type of crane available. During the work at the upper cut, high winds turned out to be a big problem. At

Figure 9. Left - work in progress charging the southern side of the upper section at a height of 90 m. The cut-out of the central pre-weakening can be seen on the left side, and part of the heavy covering can be seen on the far left. Two cranes were used when working on the covering. Right - the location of the rubble after the demolition. The photo is taken from the top of the new incineration plant, at a height of approximately 75 m.

wind speeds above 4 m/s, it proved impossible to work from the basket.

This was very challenging, both during the drilling and charging, but especially during the covering work for the upper cut.

This was remedied by a redesign of the pre-weakening and more concrete was taken out. In a very good dialogue, it was documented that the pre-weakening in the upper cut was not an issue, and it saved a lot of hard work for the contractor.

The heavy blast mats were hung up on hooks drilled into the structure above the blasting area. The blasting mats had to be fixed to the chimney by use of heavy load straps as the mats was not supposed to move when hit by gusts of wind.

The challenges presented by high winds delayed the work by one week.

5.2 Cultural differences

A number of cultural differences were observed between how structures are blasted in Denmark and in Germany:

- Normally in Denmark we remove quite a bit of the structure and check that the remaining columns to be blasted are strong enough to withstand static loads and wind until blasting is carried out, whereas in Germany it is more common to do less pre-weakening and blast a larger proportion of the structure.
- At the upper cut, where the concrete was relatively thin, the boreholes were drilled at an angle pointing 45° downwards, in order to obtain holes that were long enough to contain larger charges (i.e. fewer holes were needed) and long enough to contain both the charge and stemming material. In Germany the holes would traditionally have been drilled horizontally.
- Heavy blasting mats as covering at the upper cut would not normally have been used in Germany. In Denmark there is very little experience with blasting at a height of 90 m. At least for this project, heavy blasting mats were successfully used and no flying fragments from the upper cut were recorded.

5.3 Protection measures

To prevent damage to the surrounding buildings and utilities, several measures were put in place. A list of protection measures required as a minimum was given in the tender material. The contractor had the freedom to deploy further protection measures at his own expense, knowing that he would be liable for any damages to neighbouring properties. The minimum protection measures included earthworks, container barriers, fragment protection and dust protection.

Earthworks of sand and crushed concrete to cushion the fall of the chimney. The original plan called for a single large sand cushion for the chimney to land on. This was changed into a series of alternating dikes and ditches to save material. On the road behind the chimney, the sand was placed on top of steel plates to ease the following clean up. The road is the main access for garbage trucks to the incineration plant, so it was important to be able to use it again as soon as possible after the demolition.

Further earthworks and container barriers were placed to prevent fragments hitting nearby buildings and storage tanks.

Wooden plates were placed covering particularly vulnerable façades facing the chimney. This included the large glass panes in the site access building, and part of the transformer building where the façade consisted of thin metal panels. Also, a number of ventilation inlets at the transformer building and the powerplant were covered with plastic sheets and duct tape in order to prevent dust intrusion. Lastly, the skylights of the municipality workshop, which was the nearest building, were covered using heavy plastic sheets.

From a few hours before the blasting and until the chimney was successfully demolished, an exclusion zone was maintained, and guards were set out in order to prevent members of the public from entering the area. Guards on land were provided by J. Jensen and a boat to prevent access from the harbour was provided by the Port of Copenhagen.

The combination of the covering and the protection measures worked very well. The only damages recorded were a few small holes in a light corrugated plastic roof over a temporary workshop close to the chimney.

6 ENVIRONMENTAL IMPACTS

The environmental impacts in the form of vibrations, noise, air overpressure and dust from the demolition was monitored using a comprehensive monitoring program.

6.1 Vibrations

A forecast of the expected vibration levels was made by NIRAS during the initial studies.

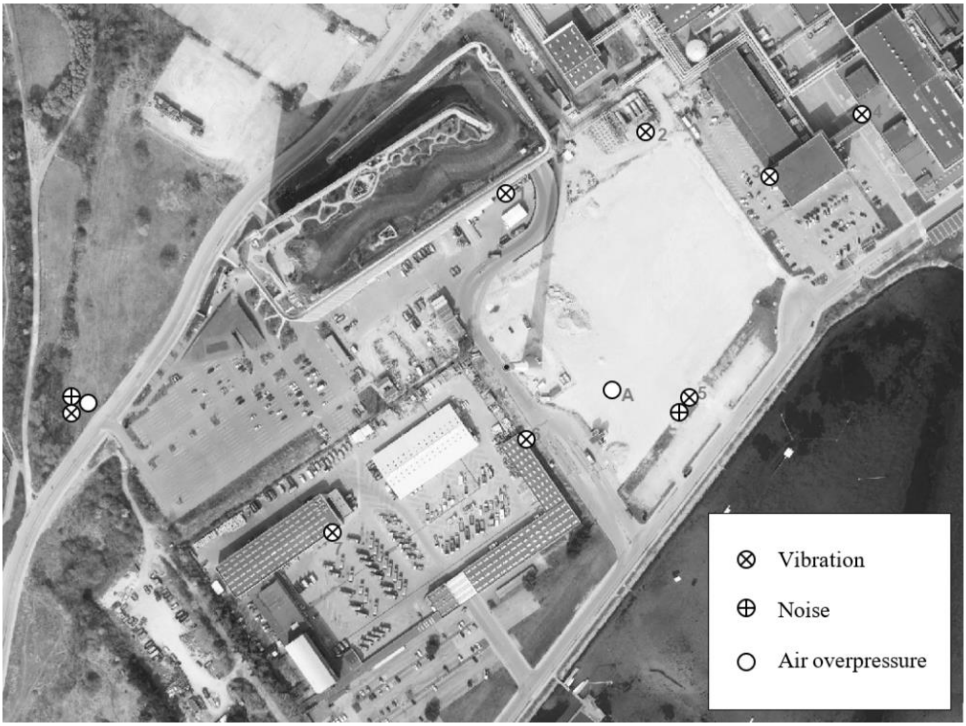

Figure 10. Measuring points for vibrations, noise and air overpressure.

The forecast was based on the method stated in DIN 4150-1. The forecast and measured maximum values are presented in Table 1.

The actual measurements were generally low compared to the estimates. The highest value of 7.8 mm/s at the municipality workshop corresponds to 39 % of the guideline value according to DIN 4150-3.

6.2 Noise and air overpressure

The noise level (L_{max}) on the technical building for district heating was measured as 114.3 dB(A), which is adjusted to 108.3 dB(A) to account for the microphone being mounted on a wall. The noise level near the residential area to the west was measured as 96.7 dB(A).

Table 1. Forecast and measurements of vibrations. The range is taken from the centre of the chimney foundation.

Location	Range [m]	Forecast [mm/s]	Max. vibration level[mm/s]
New incineration plant	105	9	4.40
Ammonia tanks	152	8	3.80
District heating main pipe (NE)	170	8	-
District heating technical building	105	11	6.10
Transformer building	220	7	2.75
Power plant	280	5	1.30
Site access building	61	11	-
Municipality workshop	48	12	7.80
Municipality storage	58	10	-
Citycontainer	167	7	2.45
Margretheholm (dwellings)	307	4	1.35

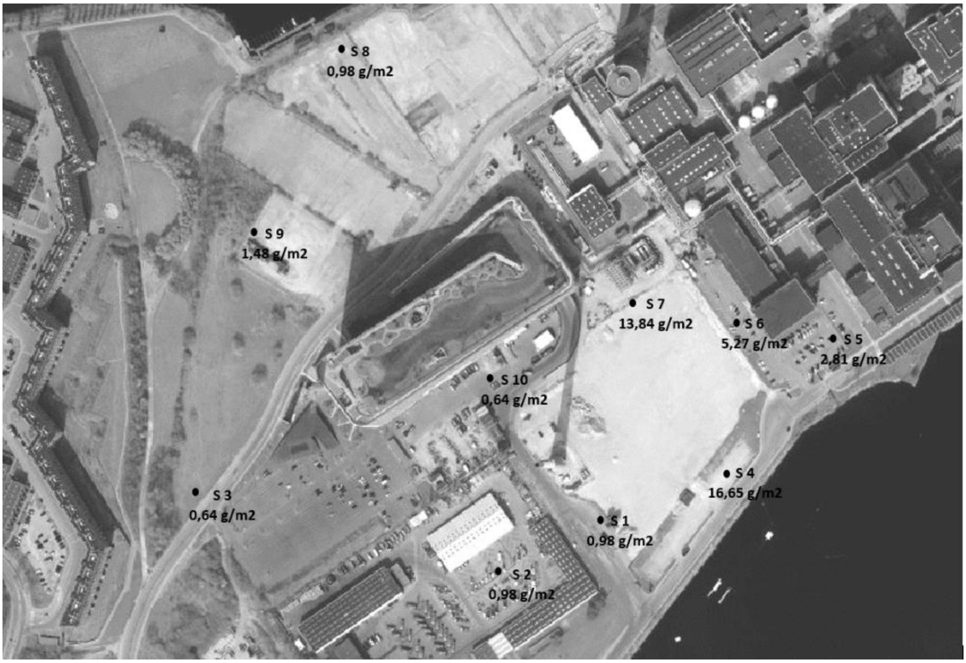

Figure 11. Amount of dust collected at various locations.

When listening to the recorded sound, both the lower and upper blast and the impact of the chimney against the ground are clearly audible, but interestingly the small detonators of the initiation system for the upper cut are also clearly audible.

45 m from the chimney the air overpressure was 229.7 Pa from the lower blast and 44.0 Pa from the upper blast. The air overpressure from the collapse of the chimney was 374 Pa.

In the area near the dwellings, the air overpressure was 8.2 Pa from the lower blast and 19.2 Pa from the upper blast. The air overpressure from the collapse after the impact of the chimney with the ground was 47 Pa.

The maximum blast induced air overpressure measured (229.7 Pa) corresponds to 92 % of the guideline value for buildings according to SS 02 52 10.

6.3 Dust

The demolition of a concrete structure of this size will naturally give off a lot of dust. Water cannons were used to reduce the amount of airborne dust, but these were only partially successful.

Several dust collection bins were set up at strategic locations all around the chimney. Dust collection was done in accordance with the Norwegian standard NS 4852:2010.

The video footage of the demolition shows that the visible dust cloud was airborne for about 3-4 minutes after the blast and that it was moving slowly in an easterly direction. As the cloud drifted out over the water, no complaints were received with regards to dust.

6.4 Reuse of concrete

The recycling of concrete rubble e.g. as base material for road construction has been done for many years, however the direct recycling into new structures has proved more difficult. The trouble is, that it is difficult to obtain concrete that is good enough to pass the quality requirements for new structures. Therefore, concrete has generally been downcycled into products of lower value than the original structure.

Recent tests in Denmark have been successful in reusing concrete as aggregate in new concrete and obtaining a result with sufficient quality to be usable in new structures. In 2018 a new waste sorting facility was built in Copenhagen using concrete with recycled aggregate.

At the time of writing, it is expected that the high quality concrete from the chimney will be used as aggregate in new concrete.

7 CONCLUSIONS

The demolition project has now successfully been concluded. The chimney fell exactly as planned and landed in the designated area. There was no damage to neighbours and the environmental impacts were well below the allowed levels.

Some of the main pointers are:

- Early dialogue with authorities and neighbours proved fruitful
- The collapse mechanism was successfully verified using a numerical simulation, which provided a higher level of confidence in the plan
- The use of heavy covering was cumbersome but was worth it
- Working from a hanging basket in high winds proved more difficult than anticipated
- Some interesting differences between normal practice in Denmark and Germany were noted
- No damages were recorded
- Environmental impacts were well below the allowed levels

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Technical and safety aspects for the demolition of a chimney with a height of 150 m in a difficult location

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ABSTRACT: The paper describes the practical way and security conditions of realising the demolition of an industrial chimney located in an oil refinery, having in its immediate vicinity sensitive equipment and constructions. The chimney has a height of 150 m and consists of the outer tubular structure of reinforced concrete and an inner chimney made of refractory brick masonry. In order to establish the possible secondary effects generated by the blasting works, a risk assessment was made with reference to seismic wave, air shock wave, noise, dust and the level of shock generated by the impact of chimney construction with the soil. The demolition work was carried out successfully and due to protection and safety measures no unwanted events were recorded, and the measured values of the seismic wave generated by the impact with the ground of the chimney were non-dangerous, being below the values estimated in the risk assessment.

1 INTRODUCTION

The restructuring of industrial activities has as a consequence the conservation or decommissioning of constructions or areas that can later be the object of the development of new projects. As a result, the demolition process using blasting works have a challenging application from the technical point of view but as well as due to the reduced time consumption, labour and cost. A large number of demolitions works by using explosives and characterised by a high degree of difficulty, have shown that the use of the blasting technique is a proper alternative from the point of view of efficiency, quality and security. The basic idea when performing a building demolition is that the destructive effect on the neighbouring structures to be protected has to be negligible, the number of elements destroyed by the blast has to be as small as possible, as well as like the explosive quantities that are blast at once.

The paper describes the practical way for the demolition of an industrial chimney located in an oil refinery, the technical and safety solutions adopted for its successful overturn in the intended direction, in very sensitive location conditions regarding the constructions and installations in its immediate neighbouring. The aim for cleaning the

Figure 1. Oil refinery platform.

area it is the construction of a new cogeneration plant for providing the oil refinery with electricity and technological steam.

In order to establish the possible secondary effects generated by the execution of the chimney demolition by blasting works, a risk assessment was made with reference to seismic wave, air shock wave, noise, dust and the level of shock generated by the impact chimney construction with the soil.

The demolition work was carried out successfully and due to protection and safety measures no unwanted events were recorded, and the measured values of the seismic wave generated by the impact with the ground of the chimney were non-dangerous, being below the values estimated in the risk assessment.

2 INDUSTRIAL CHIMNEY CONSTRUCTION DESCRIPTION

The industrial chimney was located inside a large

Figure 2. Chimney and neighbouring objectives.

Figure 3. Free space between chimney walls.

Romanian oil refinery as is shown in Figure 1, and served a thermoelectric plant in order to provide water for thermal heating and domestic hot water for the inhabitants of the city.

In the immediate vicinity of the chimney that is being demolished, there are a large number of structures and pipeline networks, the most sensitive and important of which are (Figure 2):

- to the north-west, at 120 m, 6 KV power station
- to the west, at 200 m, cooling tower
- to the south-west, at 70 m, trestle with pipes
- to south-west, at 120 m, chemical station
- to south-east, at 40 m, boiler building
- to the south-east, at 90 m, trestle with pipes
- to east, at 72 m, gas and boiler operation building
- to north-east, at 135 m, fuel depot.

The chimney has a height of 150 m and consists of the outer tubular structure of reinforced concrete, having a radius from the bottom side (level + 16 m) of 6.85 m, respectively and 5.43 m at the top side (level +150 m), as well as from the inner chimney made of refractory brick masonry with a radius of 4.65 m. The thickness of the reinforced concrete wall is variable, from 62 cm in the lower area to 21 cm at the top, while the wall thickness of the brick chimney is constant, 20 cm.

The foundation of the concrete chimney is of reinforced concrete screed type (Figure 3) with a diameter of 31.50 m and a thickness of 1.80 m, which rests at the lower level of - 4.40 m on 45 reinforced concrete piles with a diameter of 1500 mm, which have a length of approx. 36 m and is embedded in the layer of sand, limestone and sandstone. The walls of the chimney made of brick masonry are supported on a foundation with its own structure of reinforced concrete pillars of 50 x 50 cm up to a height of +14.50 and on consoles formed by the sliding wall and ring beams in the form of a wheel with spokes at each 8.00 m between elevations +14.50 and +150.00 m.

Between the reinforced concrete wall and the brick chimney wall, there is a free space used for the internal control of the structure and which in the area of elevation 16 - 25 m is about 1.6 m (Figure 3). Related structures - flue gas ducts, are made of solid brick masonry and reinforced concrete and are developed up to elevation + 17.5 m (Figure 4).

3 CHIMNEY BLAST DEMOLITION

3.1 Considerations on demolition by blasting works

Carrying out a large number of demolition works with the help of explosives, characterised by a high degree of difficulty, showed that the use of the blasting technique is a safe alternative and often the most appropriate in terms of efficiency and safety. Compared to conventional demolition procedures, the use of blasting works offers the following advantages in terms of hazards, environmental protection and work:

– blocking for a short period of time some neighbouring parts and traffic areas - periods of time limited only to the duration of the actual execution of the blasting works - compared to the usually long restrictions on the use of these spaces and areas, to demolition by conventional means
– rapid removal of the state of danger, especially where buildings are in an advanced stage of deterioration
– avoiding working at height for long periods of time
– avoiding for a long time the presence of dust, noise, vibrations, etc.

The choice of a demolishing method by blasting variants is conditioned by the physical state of the construction, by the existence of structures in the vicinity of the demolition site, by the possible effects of the demolition on these objectives. Each construction creates a special case, separately, the calculation of the blasting parameters adapting to each situation. The explosive load required for the dismantling of a certain constructive part, is dependent on the type of explosive used, the material being shot, the type of construction being demolished and the geometry of the location of the blasting holes.

The demolition process chosen must meet the following requirements:

- directing the fall to protect the nearby active structures and maintain the production/activity process
- protecting buildings near the target, against seismic action, shock wave, and throwing concrete or metal pieces under the effect of the explosion
- destroying the integrity of the construction, so that the dismantled elements can be transportable or loaded mechanically.

Figure 4. Chimney foundation and related constructions.

Figure 5. Chimney overturning direction and cut location.

3.2 The chimney demolition process

The complete tubular development of the chimney (without the existence of technological gaps such as the chimney flues) is made above the screed, starting from the elevation +17.5 m. Above elevation +14.5 m, at intervals of 8.00 m, between the sliding wall and the brick masonry wall, there are consoles formed by annular beams in the shape of a wheel with spokes. Over these reinforced concrete brackets and spokes are placed nets to facilitate staff access to inspect the condition of

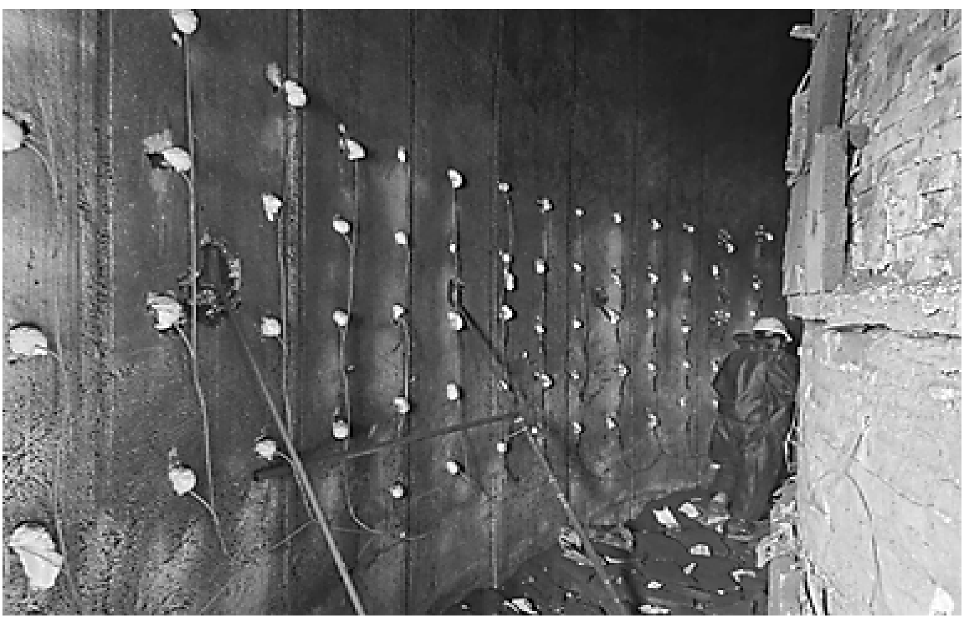
Figure 6. Cut preparation at elevation + 23 m.

Figure 7. Images of two windows at the limits of the detachment cut.

the chimney construction. The access to these platforms is made by a metal staircase arranged inside, in the free space of 1.6 - 1.0 m. When demolishing the chimney, the overturning procedure will be applied in a given direction. The existence at the elevation +23.0 m of the first visit / work platform inside the chimney, determined the choice of the area from this elevation for the execution of the chimney overturning cut (Figure 5).This platform allowed the execution of preparatory works - drilling of mine holes in the body of the concrete and brick chimney, as well as those of loading with explosives and initiation means in conditions of increased safety (Figure 6), compared to the alternative in which these works would have been executed outside the chimney from self-lifting platforms.

3.3 Preparatory stages for demolition of chimney structure

Given that in the immediate vicinity of the chimney, at a distance of 150 - 200 m in the direction North, North - East, there are no objectives to be protected, its demolition will be in this direction (Figure 5). In order to demolish the chimney structure, the following phases have been completed:

- creation by blasting works of two openings (windows) at the limits of the detachment cut, located at 2/3 of the inner perimeter, having a width of 1.2 m (corresponds to twice the thickness of the reinforced concrete wall) and a height of 1.2 m (corresponds to the height of the arrangement of four rows of holes along the length of 2/3 of the inner perimeter of the reinforced concrete chimney), Figure 7. The realisation of the two openings also served to establish the way in which the reinforced concrete structure behaves under the action of explosive loads
- realization of the detachment cut for which purpose will be drilled in the concrete wall, from inside the chimney, starting from the elevation +23.5 m, from bottom to top, 6 rows of holes placed in the square network (Figure 6 and 8), as follows:
    - row 1 of holes, starting from the elevation +23.5 m, on the opening of 1/4 of the inner perimeter of the reinforced concrete chimney (9.8 m), with a number of 23 holes. The holes will be arranged symmetrically on either side of the axis of the overturning direction
    - row 2 holes drilled above row 1 holes, on the opening of 1/2 of the inner perimeter of the reinforced concrete chimney (19.6 m), with a number of 45 holes. The holes will be arranged symmetrically on either side of the axis of the overturning direction
    - rows 3,4,5 and 6 holes drilled above row 2 holes, on the opening of 2/3 of the inner perimeter of the reinforced concrete chimney (26.2 m), with a number of 4 rows x 57 holes per row. The holes will be arranged symmetrically on either side of the axis of the overturning direction.
- drilling two rows of holes in the wall of the brick chimney inside the concrete chimney, in order to make a section for loosening the brick masonry in the area of the detachment cut. For this purpose, at elevation + 25 m, two rows of 66 holes per row will be drilled on 2/3 of the perimeter of the brick chimney (19.47 m). The holes will be arranged symmetrically on either side of the axis of the overturning direction (Figure 9)
- decommissioning in the area of the detachment cut of all additional elements such as metal stairs and lightning conductor.

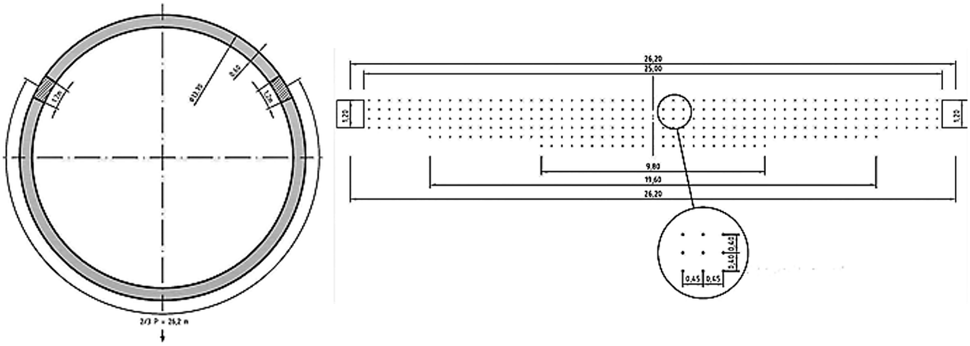

Figure 8. Diagrams of the detachment cut in the concrete wall.

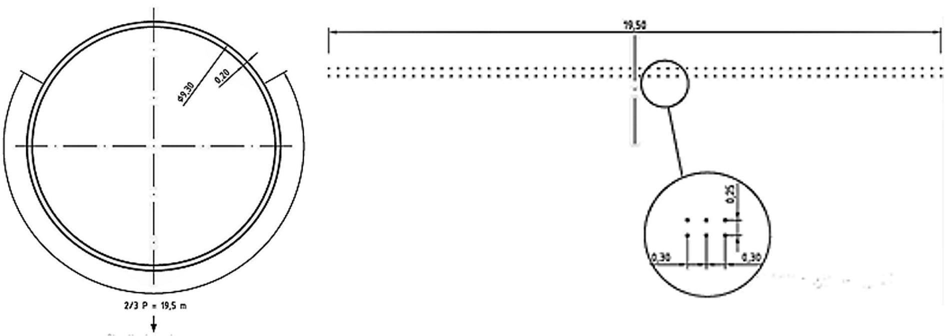

Figure 9. Section for loosening the brick masonry in the area of the detachment cut.

3.4 Blasting parameters - type of explosive and mode of initiation

The explosive charges were sized according to the section of the construction elements to be blasted. For the removal of the detachment cut in the reinforced concrete chimney, the following drilling & blasting parameters were used (Figure 8):

- wall thickness, $G_p = 0.60$ m
- burden, W = 0.30 m
- hole spacing, a = 0.45 m
- row distance, b = 0.40 m
- number of rows, N_{r1} = 4 on 2/3 of perimeter x 56 holes/row; 1 on 1/2 of perimeter x 44 holes/row; 1 on 1/4 of perimeter x 24 holes/row
- hole length, $L_h = 0.40$ m
- explosive charge per hole, $Q_h = 0.20$ kg
- total explosive charge, $Q_T = 60$ kg.

To make a loosening zone in the brick masonry chimney, the following drilling & blasting parameters were used (Figure 9):

- wall thickness, $G_p = 0.20$ m
- burden, W = 0.10 m
- hole spacing, a = 0.30 m
- row distance, b = 0.25 m
- number of rows, N_{r1} = 2 on 2/3 of perimeter x 66 holes/row
- hole length, $L_h = 0.13$ m
- explosive charge per hole, $Q_h = 0.040$ kg
- total explosive charge, $Q_T = 6.0$ kg.

In order to collapse the chimney construction in the expected direction, all the explosive charges from the concrete and brick chimneys are detonated instantly.

Dynamite type explosive loads were placed in holes and the explosive charges in each hole were initiated with detonating cord. At the cut edge, the ends of these secondary lines are connected to a

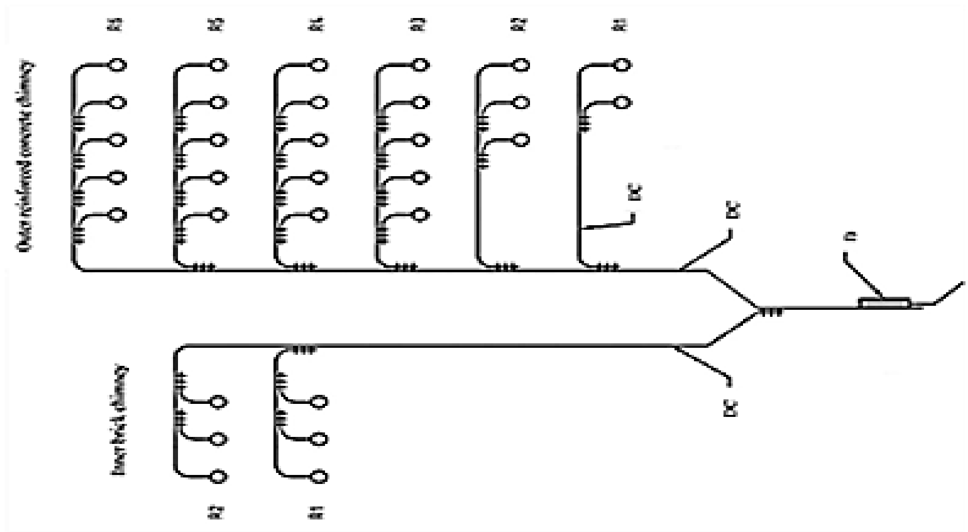

Figure 10. Initiation network.

detonating cord main line together with that one coming from brick chimney area. A non-electrical detonator was placed at the end of the detonating cord main line (Figure 10).

The total amount of explosive used to demolish the chimney construction is as follows:

- Q_{Te} = 73 kg dynamite
- Q_{Tdc} = 400 lm detonating cord
- N_d = 8 pcs of nonelectric detonators
- N_c = 10 pcs of nonelectric connectors/starters.

4 RISKS EVALUATION

The success of the demolition by blasting works is also conditioned by the solution of the protection of the civil and industrial constructions against the action of the side effects of the explosions carried out during the demolition.

Blasting activities may include:

- seismic effects generated by the detonated explosive charge
- seismic effects produced by the impact of falling on the ground of the structure that is being demolished
- overpressure
- dust and gas
- throwing pieces of material under the action of the explosion.

The industrial structures in the immediate vicinity of the chimney that was demolished are the boilers located at 40 m in a southerly direction from the chimney and the gas and boiler operation building located at 72 m in the east direction from the chimney. The two objectives being the closest to the chimney, were taken as a reference to assess the side effects of the demolition by blasting works.

The seismic effect due to the detonation of explosive charges during the chimney demolition works is negligible due to the distribution of the total charge on a number of small charges (0.040 - 0.200 kg.) placed in the structure in areas above ground.

The risk assessment showed that the oscillation velocity generated by the explosion shock, even if the explosive charges would detonate in holes drilled in the ground, is 0.370 cm/s, a value that is below 2.1 cm/s. chosen as admissible.

The impact of a collapsing structure on the ground can result in seismic effects, the magnitude of which depends on the energy released on impact. This energy depends on the mass of the structure being demolished, the height of its center of gravity and the characteristics of the ground on which it falls.

The risk assessment showed that at for the objective closest to the chimney - the boiler room, the value of the velocity of seismic waves possible to be generated at the impact of a collapsing structure of the chimney on the ground, is 1.032 cm/s, value lower than 2.10 cm/s the one chosen as permissible.

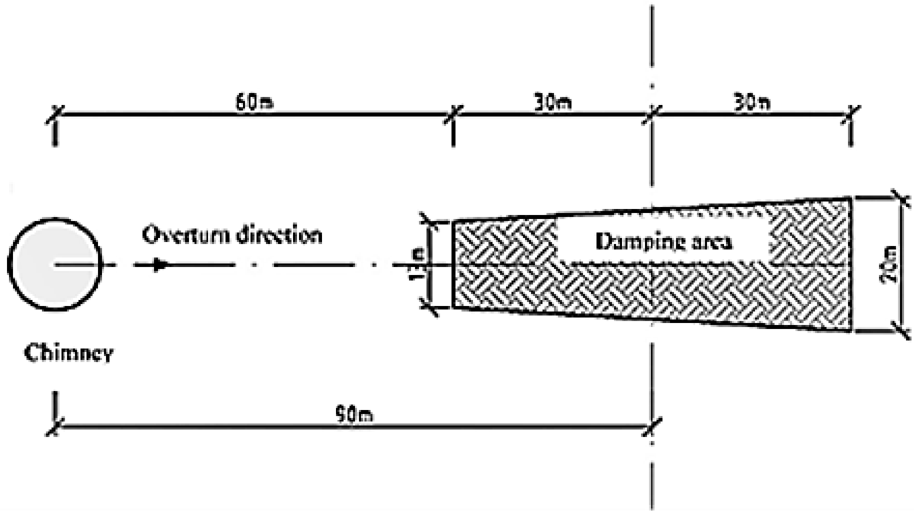

Figure 11. Damping bed arranged on the overturning direction.

In order to reduce the impact with the ground, a damping bed was arranged in the direction of overturning the chimney according to those presented in Figure 11.

In order to verify the level of vibration induced in the ground by the impact when the chimney collapsed, three seismometers were placed at the objectives considered the most sensitive. The results of the measurements are presented in Table 1 and they confirm that the seismic values induced by the collapse of the chimney are lower than the permissible ones.

Table 1. Measured vibration levels at the chimney collapse.

Measuring location	Distance from location to chimney [m]	PPV [cm/s]
Boiler room	34	0.69
Demineralisation station	122	0.27
Power station 110 kv	164	0.62

The overpressure of the shock wave also has very low values, due to the distribution of the total explosive loads over a large number of holes with small loads.

The risk assessment showed an estimated amount of overpressure value of 0.0238 Kgf/cm^2, a value which, in terms of the effects generated, is not dangerous for building or human safety. The fact that the initiation network made up of the detonating cord (the detonating cord is the component that most favours the creation of the air shock wave) is located inside the chimney, also helps to reduce the value of the air shock wave propagated around the chimney.

Environmental pollution occurs to a very small extent and is very limited in time and space of action and is due to explosive gases and dust resulting from the partial crushing of concrete. Specific to the blasting works and especially the demolition works, is the fact that the gas generating event is limited in time and number. Thus, the duration of the emission source is in the order of hundreds of milliseconds. To reduce dust pollution, the surface on which the building is to fall will be sprayed with water, both before, during and immediately after its collapse.

Throwing of small material under the effect of the explosion, is diminished by the installation at the level of the detachment cut, where the explosive charges are located, of local means of protection with materials made of welded wire mesh with large mesh, flexible wire mesh with small mesh and an external protection. of geo-textile cloth placed 0.5 m away from the construction. The external protection shall cover the area of the explosive charges, exceeding by at least 1.0 m the lower and upper part of the detachment wedge. Also, to protect the buildings in the immediate vicinity of the chimney against large pieces of material thrown or detached during

Figure 12. The sequence of the chimney collapse.

demolition, protective screens made of straw bales were placed outside them.

5 CONCLUSIONS

The restructuring of industrial activities has as a consequence the conservation or decommissioning of constructions or areas that can later be the object of the development of new projects. As a result, the demolition process using blasting works have a challenging application from the technical point of view but as well as due to the reduced time consumption, labor and cost. A large number of demolitions works by using explosives and characterised by a high degree of difficulty, have shown that the use of the blasting technique is a proper alternative from the point of view of efficiency, quality and security.

Each construction creates a special case, the calculation of the blasting parameters is adapted according to each specific situation. Blasting parameters and explosive charges are sized according to the type of material and section of the construction elements to be blasted.

The most commonly used method of demolition is the collapse of the construction itself or overturning in a given direction. For this purpose, numerous works of structural preparation, removal or reduction of the section of constructive elements are made beforehand.

All these approaches are described in this paper and based on the blasting concept and risk assessment needed to be taken in consideration, it is presented the practical way of realizing with success the demolition by blasting works (Figure 12 and 13) of an industrial chimney with 150 m height located inside of an oil refinery and in the immediate vicinity of sensitive structures.

Figure 13. Chimney after demolition.

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