FDTAS D&B QUICK REFERENCE 003

UNDERGROUND DEVELOPMENT ROUNDS

FROM DRIVE DIMENSIONS TO DRILL PATTERN

A practical first-pass method for developing an underground drill-and-blast round from excavation dimensions, hole diameter, drilling accuracy, explosive characteristics and required advance.

PURPOSE OF THIS REFERENCE

This guide brings together established Swedish-model relationships for four-section parallel-hole cuts, general tunnel-round geometry and practical field checks. It is intended to help an experienced drill-and-blast practitioner build and audit a rational starting design - not to replace site-specific engineering, statutory controls or approved blast procedures.

DESIGN INPUT	EXAMPLE USED IN THIS GUIDE
Drive profile	5.0 m wide x 5.0 m high
Charged hole diameter	45 mm
Empty / reamed hole diameter	152 mm
Planned hole depth	4.2 m
Cut type	Four-section parallel-hole burn cut
Illustrative rock condition	Competent hard rock
Initiation	Electronic / millisecond sequencing - site engineered

CUT → EASERS / STOPING → WALLS & CROWN → LIFTERS

1. Start with the excavation - not the hole pattern

An underground development round has only one initial free face: the exposed face of the drive. The cut must create a second free face before the rest of the round can break efficiently. For this reason, the face should be divided into functional zones rather than treated as one uniform burden-and-spacing grid.

ZONE	PRIMARY JOB	DESIGN EMPHASIS
Cut	Create the initial void	Relief diameter, drilling accuracy, charge concentration
Easers / stoping	Expand the void	Burden, spacing, progressive relief
Walls / ribs	Form final profile	Reduced damage, controlled charge
Crown / back	Control excavation limit	Contour quality, overbreak
Lifters / floor	Establish floor and clear toe	Heavier confinement, floor level, muck movement

2. Establish the basic design inputs

Drive width and height, profile and required excavation area.
Charged-hole diameter and available reamer / empty-hole diameter.
Maximum practical drill length and expected hole deviation.
Explosive density, cartridge / bulk diameter, relative or absolute strength and achievable linear charge concentration.
Rock mass structure, strength, joint orientation and likely blastability.
Required advance, profile tolerance, overbreak limit and downstream fragmentation requirement.
Available initiation system and site-specific timing / vibration constraints.

FDTAS FIELD NOTE

The cut controls the round. If the cut does not open, the remainder of the face is attempting to break into confinement. Before changing every burden and spacing on the face, establish whether the cut actually created the void assumed by the design.

3. Target advance and hole depth

$$I = 0.95\ H$$

I = average advance (m); H = drilled hole depth (m). The 95% relationship is a design target associated with well-controlled parallel-hole rounds, not a guarantee.

For the 4.2 m worked example: **I = 0.95 x 4.2 = 3.99 m target advance.**

$$\text{Pull (\%)} = \text{Actual advance} / \text{Drilled hole length} \times 100$$

Use actual surveyed advance to calibrate the round.

4. Check whether the relief hole can support the planned depth

For the four-section parallel-hole model, a published relationship links practical hole depth to empty-hole diameter:

$$H = 0.15 + 34.1\,D_0 - 39.4\,D_0^2$$

D_0 = empty-hole diameter in metres; published applicability $0.05 \le D_0 \le 0.25$ m.

Worked example - 152 mm empty hole: **$H \approx 0.15 + 34.1(0.152) - 39.4(0.152^2) = 4.42$ m.**

A planned 4.2 m round therefore sits below the empirical depth indicated by this relationship. By comparison, a 102 mm relief hole gives only about 3.22 m from the same equation.

IMPORTANT

The relationship is empirical. It does not compensate for poor drilling accuracy. A large relief hole cannot rescue a cut in which charged holes converge, diverge or collar inaccurately.

5. First quadrangle - establish the critical burden

The first charged holes break toward the circular empty hole. Literature recommends keeping the first burden below about $1.7D_0$; a common starting value is:

$$B_1 \approx 1.5\,D_0$$

Simple starting geometry where drilling accuracy is good.

For $D_0 = 0.152$ m: **$B_1 \approx 1.5 \times 0.152 = 0.228$ m.**

Where drilling deviation is significant, the practical first burden can be reduced:

$$B_1 = 1.7\,D_0 - (\alpha_e H + \beta_e)$$

α_e = angular deviation (m/m); β_e = collaring deviation (m).

Illustrative deviation check: $\alpha_e = 0.005$ m/m (0.5%), H = 4.2 m, $\beta_e = 0.010$ m. **Maximum positional error = $0.005(4.2) + 0.010 = 0.031$ m; $B_1 \approx 0.227$ m.**

6. Cut opening geometry

$$W_1 = B_1\sqrt{2}$$

W_1 = side length of the first quadrangle.

$$B_n \approx 0.7\,W_n \quad \text{and} \quad W_{n+1} \approx 1.7\,W_n$$

Use the opening created by the previous section as the free face for the next section.

The cut therefore grows progressively outward. The exact number of sections should be checked against the required opening and the available face area.

7. Cut charge concentration

The Swedish-model relationship for the linear charge concentration of the cut links hole diameter, burden, empty-hole diameter, rock constant and explosive strength:

$$q = 55\ d_h\ (B/D_0)^{1.5}\ (B - D_0/2)\ (c/0.4)\ /\ RWS$$

q = linear charge concentration (kg/m); d_h and D_0 in metres; B in metres; c = rock constant; RWS = relative weight strength to ANFO.

Illustrative first-quadrangle calculation using d_h = 0.045 m, D_0 = 0.152 m, B = 0.227 m, c = 0.4 and RWS = 1.0: **q ≈ 0.69 kg/m.**

DO NOT COPY THE EXAMPLE CHARGE

The numerical example demonstrates the calculation only. Actual charge diameter, explosive density, energy, coupling, water conditions, statutory limits and supplier data must be checked before a site design is issued.

8. Move from the cut to the remainder of the face

Once the cut geometry is established, the rest of the round can be designed from the available bottom charge concentration. Olofsson's published relationship is:

$$B = 30\ q_\beta\ /\ d_h$$

B = burden (m); q_β = bottom charge concentration (kg/m); d_h = blasthole diameter (mm).

For fully coupled cylindrical explosive, the theoretical mass per metre can be checked from cross-sectional area and density. The published Swedish formulation also applies an explosive strength factor. Use the supplier's actual density and energy data rather than assuming a generic product.

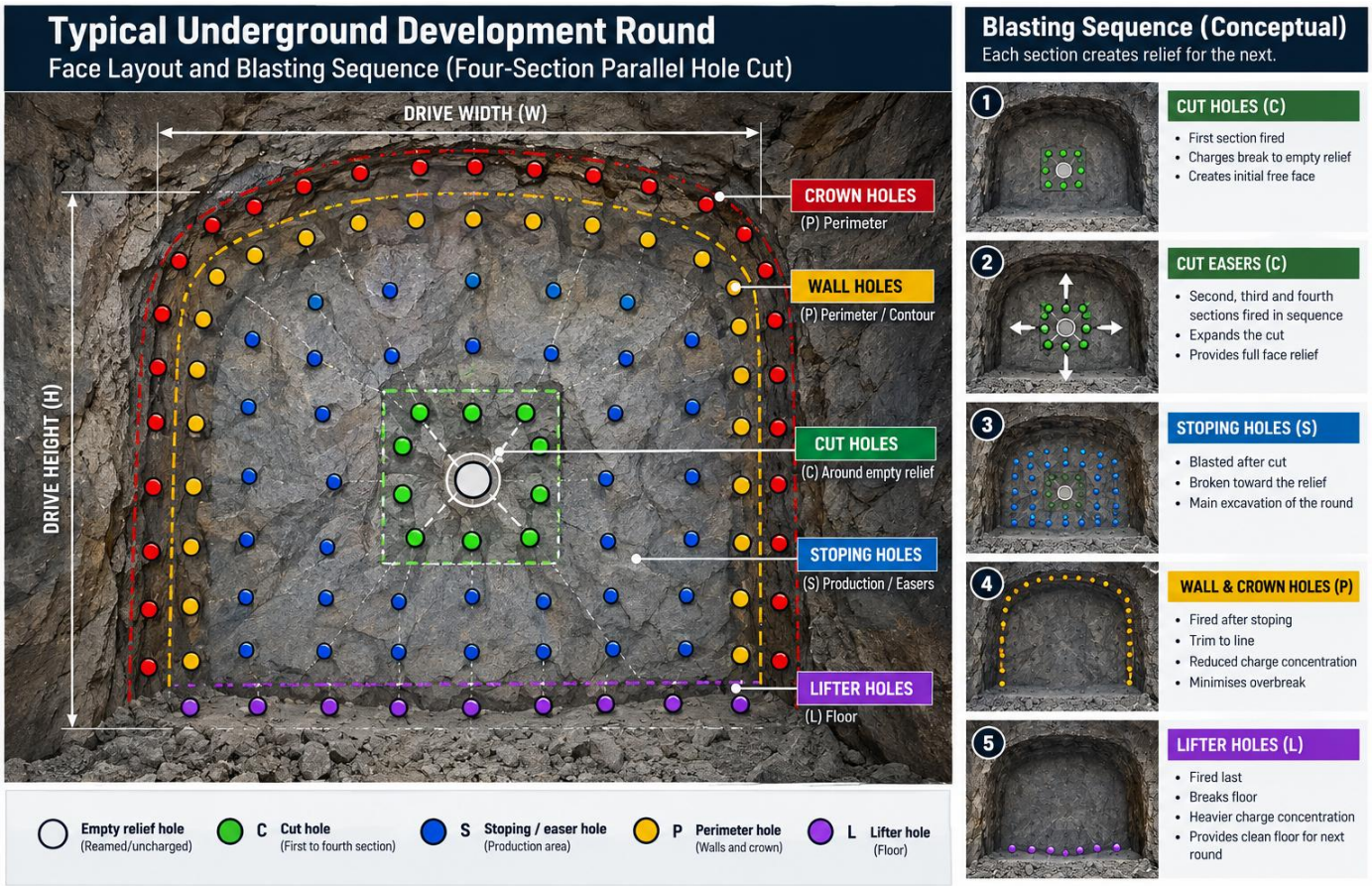
9. Zone-by-zone geometry

PART OF ROUND	BURDEN	SPACING	BOTTOM CHARGE LENGTH	COLUMN CHARGE	STEMMING
Stoping - upward / horizontal	B	1.1B	H/3	0.5 q_β	0.5B
Stoping - downward	B	1.2B	H/3	0.5 q_β	0.5B
Roof / crown	0.9B	1.1B	H/6	0.3 q_β	0.5B
Walls / ribs	0.9B	1.1B	H/6	0.4 q_β	0.5B
Floor / lifters	B	1.1B	H/3	1.0 q_β	0.2B

These are model relationships for a first-pass design. Perimeter-control practice may deliberately use closer spacing, decoupled charges or different charge distributions to meet overbreak and damage objectives.

10. Face layout - think in zones

A practical face layout should make the sequence of relief obvious. The sketch below is conceptual - it is not a drill plan.



11. Perimeter holes - profile control is a separate objective

Walls and crown should not automatically receive the same energy concentration as production holes. The design objective changes from maximum breakage to controlled breakage at the excavation limit.

Use the required final profile to set collar positions and lookout.
Control linear charge concentration and coupling to limit damage beyond the excavation line.
Track half-barrels, overbreak, underbreak and visible back damage after every round.
Separate geology-driven overbreak from drilling and charging errors before changing the pattern.

FDTAS FIELD NOTE

A clean contour is not achieved by spacing alone. Hole alignment, charge distribution, coupling, initiation and geology all matter. Measure the actual profile rather than judging the wall only by appearance.

12. Lifters - the holes that determine tomorrow's floor

Lifters work under greater confinement and must break against the weight of the rest of the round. Poor lifter performance leaves toes, high floor and difficult collaring conditions for the next round.

CHECK	WHY IT MATTERS
Lifter burden / spacing	Controls toe breakage and floor continuity
Hole angle and toe position	Determines final floor level and avoids cumulative ramping
Charge concentration	Must overcome confinement without excessive floor damage
Initiation position in sequence	Requires adequate relief from the rest of the round
Muck movement	Influences clean-up, loader productivity and next-face access

13. Timing - design the sequence around relief

There is no single universal millisecond delay that is correct for every drive. Timing should preserve the intended sequence of cavity creation and rock movement.

$$\text{CUT} \rightarrow \text{CUT EXPANSION} \rightarrow \text{STOPING} \rightarrow \text{CONTOUR} \rightarrow \text{LIFTERS}$$

The actual delay intervals must be engineered for the initiation system, burden movement, vibration limits, face geometry and site conditions.

The first cut must create usable void before the next section relies on it.
Successive cut sections should enlarge the opening rather than compete for the same limited relief.
Stoping holes should progressively break toward the established opening.
Contour timing should support profile control and avoid unnecessary damage.
Lifters are commonly late in the round so that broken material above them has already gained relief.

TIMING WARNING

Delay numbers should not be copied from a generic table without site verification. Electronic detonators allow precise sequencing, but precision does not make an unsuitable sequence correct.

14. V-cut alternative

Where an angled cut is preferred, the V-cut can reduce the need for a large reamed relief hole but requires sufficient drive width and accurate angle control. Published Swedish-model relationships include:

$$B = 30\, q_\beta\, f / d_h \quad \text{and} \quad E \approx 0.8\, B$$

f corrects for cut-hole angle; published examples use f = 1.0 at 60°, 1.1 at 75° and 1.2 at 90°.

Theoretical advance is constrained by cut geometry and drive width. For narrow drives or long rounds, a parallel-hole cut may provide a more practical route to high pull when drilling accuracy is available.

15. Worked design workflow - 5 m x 5 m drive

STEP	WORKED EXAMPLE / DECISION
1. Define profile	5.0 m x 5.0 m development drive
2. Select drill system	45 mm charged holes; 152 mm reamed relief
3. Select hole depth	4.2 m
4. Set target advance	0.95H = 3.99 m
5. Check relief-hole depth relationship	152 mm gives empirical H ≈ 4.42 m
6. First cut burden	$B_1 \approx 0.228$ m; deviation-adjusted example ≈ 0.227 m
7. First cut opening	$W_1 = B_1\sqrt{2} \approx 0.322$ m
8. Expand cut	Use $B_n \approx 0.7W_n$ and $W_{n+1} \approx 1.7W_n$ as first-pass geometry
9. Establish charge concentration	Use actual explosive properties and cut-charge equation
10. Calculate stoping burden	From actual q_β and hole diameter
11. Apply zone factors	Stoping, crown, walls and lifters designed separately
12. Establish timing logic	Progressive relief; site-specific delays
13. Check total holes / metres / explosive	Confirm operational and economic practicality
14. Fire, survey and calibrate	Use measured pull, profile, fragmentation and floor performance

16. What to measure after every round

MEASURE	QUESTION IT ANSWERS
Actual advance / pull	Did the cut and round achieve the planned depth?
Cut cavity / bootlegs	Did the cut open as designed?
Hole deviation	Did the toe geometry match the collar design?
Overbreak / underbreak	Did perimeter control meet profile tolerance?
Half-barrels / visible damage	How did the contour perform?
Floor level / toes	Did the lifters establish the required floor?
Fragmentation / oversize	Is the stoping pattern suitable for mucking and downstream handling?
Muckpile shape and diggability	Did timing and movement support loading?
Explosive kg per round / m^3	Is the energy input economically rational?
Drilled metres per metre advance	Is the pattern efficient, not merely effective?

THE OPTIMISATION LOOP

Design → drill → measure → fire → survey → compare → adjust one controlled variable → repeat. A successful underground pattern is site-calibrated, not copied.

17. Common failure modes - problem → likely cause → check

OBSERVATION	LIKELY DESIGN / EXECUTION ISSUE	FIRST CHECK
Poor pull / frozen face	Cut did not establish adequate void	Relief diameter, cut burden, deviation, cut charge
Bootlegs in cut	Burden too large or cut holes misplaced	Toe positions and drilling deviation
Cut crushed but not ejected	Burden too small / insufficient void / timing	Relief volume and cut sequence
High floor / toes	Lifter geometry or energy insufficient	Lifter toe position, burden, charge
Excess crown overbreak	Perimeter energy or drilling control too high/poor	Lookout, alignment, linear charge
Coarse stoping fragmentation	Burden/spacing too large or poor relief	Actual free face and explosive distribution
Tight muckpile	Insufficient movement / timing interaction	Sequence and available relief
Round works inconsistently	Execution variability exceeds design tolerance	Collaring, deviation, charging QA/QC

18. FDTAS design checklist

Drive profile and excavation tolerance confirmed.
Hole diameter, reamer diameter and achievable drill depth confirmed.
Drill deviation measured - not assumed.
Cut type selected to suit drive width, drill equipment and required advance.
Cut burden checked against relief diameter and drilling error.
Explosive density / strength / linear charge confirmed from current product data.
Stoping, perimeter and lifter zones designed separately.
Timing sequence supports progressive relief.
Total drilling and explosive consumption checked against production requirements.
Survey and blast-performance data prepared before the first optimisation change.

Technical information disclaimer

Information in this FDTAS Quick Reference is intended for general technical reference, education and professional development. It does not constitute a site-specific blast design, firing instruction or substitute for competent professional judgement. Underground blasting and explosives operations must only be undertaken by suitably trained, qualified and authorised personnel in accordance with applicable legislation, approved site procedures, risk assessments and manufacturer requirements. All equations and empirical relationships must be checked against site geology, drilling capability, explosive properties and regulatory constraints before application.

References & further reading

Yilmaz, O. (2023). Drilling and blasting designs for parallel hole cut and V-cut method in excavation of underground coal mine galleries. Scientific Reports 13, 2449. DOI: 10.1038/s41598-023-29803-6.
U.S. Army Corps of Engineers (2018). EM 1110-2-3800 - Blasting for Rock Excavations. Tunnel blasting sections include burn cuts, V-cuts, timing, perimeter holes and advance.
U.S. Army Corps of Engineers. EM 1110-2-2901 - Tunnels and Shafts in Rock. General tunnel drilling, free-face, cut and perimeter principles.
Olofsson, S.O. Applied Explosives Technology for Construction and Mining. Underground blasting / tunnelling design relationships.
Holmberg, R. / Persson et al. Swedish tunnel-blast design model: four-section parallel-hole cut, stoping, contour and lifter design.
Chakraborty et al. / later comparative literature on tunnel blast design models. Use site calibration and measured performance when selecting between parallel-hole and angled cuts.