Appendix

1. Damage level ratings

The practical implication of excavation or support damage strongly depends on the inflicted damage level by excessive load, displacement or energy demands. The following rating tables were developed for dynamic loading conditions based on Kaiser et al. (1992) and Heal et al. (2006).

For this purpose, it essential to differentiate between damage or failures caused by dynamic acceleration triggering or causing shakedown failures and those caused by static or dynamic rock mass deformation and associated displacement-driven failure of support components.

1. Shakedown damage dominated by dynamic acceleration

A shakedown is a rockburst that causes damage to an excavation or its support by a seismically induced fall of ground. A fall of ground that is not triggered by a seismic event is not a rockburst.

Shakedown damage indicators:

1. Unsupported ground:
* Rock blocks or fragments from stress-fractured ground are located below original location (near wall for shakedown from walls, i.e. immediately below origin).
* No floor heave.
1. Supported ground:
* Rock blocks or fragments from stress-fractured ground in mesh or behind bulged shotcrete.
* Surface support failed and rock blocks or fragments from stress-fractured ground are located below original location.
* No floor heave.

Table A1

Shakedown (SD) damage scale.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Rockburst damage scale | Rock mass damage and displaced rock | Damaged surface support area | Rock support damage | Preventive support maintenance (PSM) |
| R0SD | No signs of damage at all | 0 | No signs of damage at all | No deformation-based PSM action possible |
| R1SDClear indication of shaking motion | No damage, minor loose or shards of rock or shotcrete displaced | 0 | No damage to support system  | No deformation-based PSM action possible |
| R2SD | Rock mass unravelled;< 1 t displaced (small blocks or fragments)  | If supported, surface support generally retains broken rock; locally open between rock bolts< 1 m2 failed/open | Support system shows signs of loading, loose in mesh or behind shotcrete, shotcrete is cracked, plates maybe locally deformed | PSM focused on restoration of AS capacity |
| R3SD | Rock mass unravelled involving dm3 blocks;1–10 t displaced(no signs of ejection) | 1–10 m2 loaded/bulged surface support:< 3 m2 failed/open surface support (involving failure at ≥ 1 bolt plate) | Some broken bolts and fractured shotcrete; bulged mesh- or fibre-reinforced shotcrete | Local SSC compromised: PSM focused on replacement of holding/ load capacity, replacement of rock mass reinforcement and restoration of AS capacity. |
| R4SD | Rock mass unravelled involving ft3 and geological structures;10–100 t displaced(no signs of ejection) | 3–30 m2 failed/open | Major damage to support system; SSC severely compromised in roof or at least one wall | Overall SSC compromised: PSM focused on replacement of displacement/ energy capacity, replacement of deep rock mass reinforcement and restoration of AS capacity.  |
| R5SD | Rock mass unravelled involving m3 and geological structures;100+ t displaced(no signs of ejection) | > 30 m2 failed/open | Complete failure of support system involving roof and wall(s) | PSM cannot be applied; excavation has to be repaired, i.e. re-supported after removal of failed AS and reinforced rock. |

Note: PSM aims at adding support capacity without rehabilitation involving removal of broken rock and highly stressed or partially damaged support.

1. Damage by strainburst dominated by static and dynamic bulking of stress-fractured ground

A strainburst is an excavation failure process whereby substantial stored strain energy is released from failing a burst volume near the excavation (energy release from burst volume and surrounding rock mass). This may include burst volumes in the floor leading to floor heave.

Strainburst damage indicators:

1. Unsupported ground:
* Stress-fractured ground is ejected (deposited beyond angle of repose).
* Floor heave due to tangential stress in floor (possibly combined with upward acceleration from the distant seismic event).
1. Supported ground:
* Effective support systems show bulking or translational deformation; the initial velocity may eject slabs of shotcrete (shotcrete rain) or shotcrete/rock fragments may be retained in mesh.
* If the support is ineffective, i.e. surface or support systems are locally open, rock fragments may be ejected and deposited beyond angle of repose.
* Floor heave due to tangential stress in floor.
* Roof rock fracturing or floor heave due to punch failure of well-supported walls.

Table A2

Strainburst (SB) and bulking damage scale.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Rockburstdamage scale | Rock mass damage and displaced rock | Floor heave | Damaged surface support area | Rock support damage | Preventive Support maintenance (PSM) |
| R0SB | No signs of damage at all |  | 0 | No signs of damage at all | No PSM action |
| R1SBindication of strong shaking  | No damage, minor loose or shards of rock or shotcrete displaced |  | 0 | No damage to support system; no rock or shotcrete fragments displaced  | No deformation-based PSM action. However, R1SB suggests that SB damage risk is elevated |
| R2SB | < 1 t displaced stress-fractured rock |  | If supported, surface support retains broken rock; locally open between rock bolts< 1 m2 failed/open;small (< 1dm2) spalls of shotcrete displaced | Support system shows signs of loading, loose in mesh or behind shotcrete, shotcrete is cracked, plates maybe locally deformed | PSM focused on restoration of AS capacity |
| R3SB | 1–10 t displaced stress-fractured rock | and/or minor< 0.1 m | 1–10 m2 loaded/bulged surface support;< 3 m2 open/failed at ≥ 1 bolt plate(few signs of ejection) | Some broken bolts and fractured shotcrete; bulged mesh- or fibre-reinforced shotcrete; shotcrete shakedown or ejection (1 dm2 - 1 m2) | Local SSC compromised: PSM focused on replacement of holding/ load capacity, and rock mass reinforcement. Restoration of AS capacity. Typically applied at observed wall convergence >50 to 75 mm. |
| R4SB | 10–100 t displaced stress-fractured rock; possibly with unravelled blocky ground and involving geological structures | and/or moderate≤ 0.5 m | 3–30 m2 open (signs of ejection) | Major damage to support;SSC severely compromised in roof or one wall | Overall SSC compromised: PSM focused on replacement of displacement/ energy capacity, and deep rock mass reinforcement. Restoration of AS capacity. Typically for observed >100 to 125 mm. |
| R5SB | 100+ t displaced stress-fractured rock; involving geological structures / unravelled blocky ground | and/or severe> 0.5 m | > 30 m2 open(signs of ejection) | Complete failure of support system involving roof and wall(s) | PSM cannot be applied; excavation has to be re-supported by rehabilitation with removal of failed reinforced rock and re-supported. |

Note: PSM aims at adding support capacity without rehabilitation involving removal of broken rock and highly stressed or partially damaged support.

References

Heal, D., Potvin, Y., Hudyma, M., 2006. Evaluating rockburst damage potential in underground mining. In: Golden Rocks 2006, The 41st U.S. Symposium on Rock Mechanics (USRMS): "50 Years of Rock Mechanics - Landmarks and Future Challenges". Paper 1020.

Kaiser, P.K., Tannant, D.D., McCreath, D.R., Jesenak, P., 1992. Rockburst damage assessment procedure. International Symposium on Rock Support, A.A. Balkema, Rotterdam, pp. 639-647.