Bearing Plates: New Developments in the Unsung Heroes of Ground Support

P Gray[1]

ABSTRACT

The trend in the mining industry over the past ten years has been to use higher capacity ground support systems. Much of the engineering design and development for these high capacity ground support systems has focussed on new, more effective, and stronger rock bolts and cable bolts. However, higher capacity rock bolts or cable bolts are only part of the solution to ground support problems, and it is now apparent that a total systems solution is required which addresses such issues as: speed of installation; safety; cost; rib support as well as roof support; and, the interaction of different ground support products. This last factor has received very little attention in the past, and applies particularly to the interaction of bolts, mesh or straps, and, bearing plates. Bearing plates are a fundamental and integral part of any rock support system.
The capacity of bearing plates should be matched to the capacity of the rock bolts or cable bolts that they are used with, and they should be designed not to damage other support systems such as mesh or straps. This paper gives examples of both good and bad bearing plate installations, and indicates trends for the future.

BACKGROUND

The original function of bearing plates was to retain and support the rock immediately underneath the bearing plate, and to prevent the nut or forged head on the end of the rock bolt from being "pulled" into the rock bolt hole. Early bolts used in the underground coal industry were point anchored "slot and wedge" bolts, and these were used with basic bearing plates which were simply flat, square pieces of steel with a central hole to accommodate the rock bolt.
Subsequently, a wide variety of different types of bearing plates have been developed for rock bolts and cable bolts for the mining and tunnelling industries. These have included square and round plates, and even triangular plates have been developed. Today, most bearing plates also accommodate uneven roof conditions by allowing angular movement between the bolt and the plate, either by:

- using a domed ball which will rotate around the central hole in the bearing plate; or by,
- using two hemispherical plates which will rotate over each other; or by,
- using a deformable plate that will distort to accommodate such angular movement.

Most bearing plates are pressed plates, but thicker plates (>15mm thick) are normally machined and/or fabricated. The majority of bearing plates used in the coal industry are square domed plates which use a domed ball to allow angular movement, and are typically 8mm, 10mm or 12mm thick. Square domed plates are simple to manufacture, have a minimal steel wastage, and their bearing capacity can be increased by making them thicker.

Recent trends in ground support

The trend in the mining industry over the past ten years has been to use higher capacity ground support systems including rock bolts and cable bolts. The reasons for this are firstly, that ground conditions have become more difficult in many mines; secondly, that the "materials cost" of bolts is much less than the "total installed cost" of bolts and therefore there is an advantage in using fewer, but stronger bolts; and lastly, that mining methods and systems have resulted in higher stresses in many mines necessitating higher capacity support systems.

---

[1] BHP Engineering Pty. Ltd. Wollongong

In addition, the trend for long tendon support using cable bolts, and the increase in pre-tensioning for both cable bolts and rock bolts, has resulted in greater loads being generated at the collar of the bolt and hence onto the bearing plate.
However, much of the engineering design and development for the ground support industry has focussed on new, more effective and stronger rock bolts or cable bolts but there has been less engineering design or analysis undertaken for bearing plates, and yet they are a fundamental and integral part of any rock support system.

It is also now becoming clear that new rock bolts or cable bolts are only part of the solution to ground support problems, and it is apparent that a total systems solution is required which addresses such issues as: speed of installation; automation; safety; cost; rib support as well as roof support; and, the interaction of different ground support products. This last factor has received very little attention in the past, and applies particularly to the interaction of bolts, mesh or straps, and, bearing plates.

This paper is concerned with the performance of bearing plates, and outlines some design criteria that should be used for bearing plates.

THE TOTAL INSTALLED COST OF ROCK BOLTS

The cost of ground support is a significant investment for any mining operation. This investment is much greater than the "total materials cost" of rock bolts alone, and is closer to the "total installed cost" of rock bolts. However, if roof falls occur, then the total cost of ground support could be much higher than the total installed cost of rock bolts alone (ie costs to clean-up the fall, costs of delays etc). Galvin and Pallas (1997) estimated that there are 10 major falls in the underground coal industry each year in Australia with a total cost approximately $10 million for each fall. In addition, there are costs associated with injuries sustained during roof falls or when cleaning up roof falls. It is therefore vital that the investment in ground support be optimised, such that the lowest overall ground support cost can be achieved.

It is important to recognise what the total installed cost of rock bolts actually is. Firstly, a basic rock bolt itself costs only about $8 to $12 depending upon length and type (this excludes cable bolts and specialist high strength bolts). Secondly, the costs of the other materials required to go with a rock bolt are approximately another $11, eg a bearing plate, a resin cartridge, and a proportional cost of: mesh or straps; drill rods; and drill bits. This brings the total materials cost to a minimum of $19 per bolt.

In addition, there are the costs of labour to install the bolt (approximately $6 per bolt, but can be much higher particularly for cable bolts). Moreover there are the costs of the equipment to install the bolt such as depreciation and maintenance costs (estimated at a minimum of $2 per bolt), but excluding running costs. Finallý, there are the costs associated with the delays caused by rock bolting (ie the cost of the lost production caused by rock bolting and this will vary between different mines but is approximately $75 per bolt). These costs are shown in Fig. 1 and gives the total installed cost as $102 per bolt!

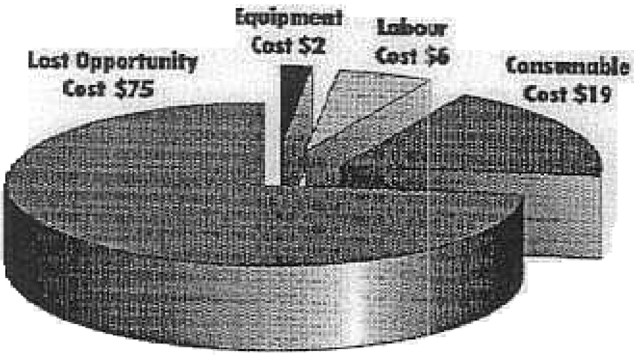

Fig. 1 - Pie Chart showing the Total Installed Costs of Rock Bolting

Note: The assumptions made above in relation to the Total Installed Cost of Rock Bolts are conservative. Different assumptions made in relation to the number of bolts and the total time taken to install bolts, can increase the total installed cost significantly.

This basic model was re-run several times for different mines with different assumptions and the range in costs was from $80 per bolt to nearly $300 per bolt. Therefore the total installed cost for a $8 to $12 rock bolt is approximately $100 each (ie 10 times the cost of the bolt itself and 5 times the total materials cost). The obvious conclusions are that:

- the cost of the bolt itself is insignificant compared to the total installed cost;
- installing fewer, stronger (but more expensive) bolts would save significant costs;
- installing the same number of cheaper bolts would have minimal cost savings;
- installing more (but less expensive) bolts would dramatically increase costs;
- it is essential to achieve the maximum performance from each bolt installed by using the correct installation procedure and with the use of matched components.

This last point applies to all components used for the installation of rock bolts including resin, straps or mesh and, importantly, bearing plates. Bearing plates are particularly important because they have the potential to damage other components of the rock bolt system, and ultimately cause failure.

THE DESIGN AND PERFORMANCE OF BEARING PLATES

The performance of bearing plates should be considered in terms of their:

- Ultimate load capacity;
- Load/Deformation characteristics;
- Interaction with other support components (bolts, cables, straps, mesh etc);
- Interaction with the roof rock mass; and,
- Ease of installation.

In addition, the design of bearing plates should consider the cost of manufacture.

Ideally, bearing plates should provide stiff confinement to the rock mass immediately under the collar of the rock bolt, as well as between rock bolts. This would require bearing plates to be very thick, very large, and be linked together with each other. In reality, this is impractical but the use of mesh and straps can help to support the rock mass over a larger area than is possible with bearing plates alone. Therefore the design of the bearing plate needs to be considered in relation to the other support systems it is used with (eg mesh, straps, etc).

Matching bolts and plates

In addition, bearing plates themselves should be designed to have the same ultimate load capacity as the bolts they are used with. For example, a common high strength rock bolt may have an ultimate tensile capacity of approximately 30-33 tonnes, but these are almost always used with bearing plates with an ultimate bearing capacity of only 18-20 tonnes. This is equivalent to using rock bolts which have half of their section machined away at the collar of the bolt (such a bolt is shown in Fig. 2). It would be unthinkable to use the rock bolt that is shown below, but many local mines do exactly that by using high strength rock bolts with bearing plates that only have half the capacity of the rock bolt.

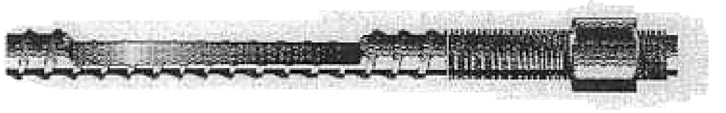

Fig. 2 - Most mines use rock bolts that have the strength equivalent to the bolt shown above.

This is analogous to using a chain with one weak link. From an engineering and safety aspect one would never use a chain with one weak link, so why do we do it in the ground support industry? One argument that supports this point of view is that for fully encapsulated bolts, high collar loads are not generated and therefore high capacity bearing plates are not required. However, geological and stress conditions can never be absolutely determined. In addition, the installation of bolts and the mixing of resin anchors is never 100% reliable. Therefore it is possible to have high collar loads on bolts even with fully encapsulated bolts in mines with good roof conditions.

Fig. 3 shows a common square bearing plate that has failed completely by splitting and turning inside out even though the bolt itself has not failed.

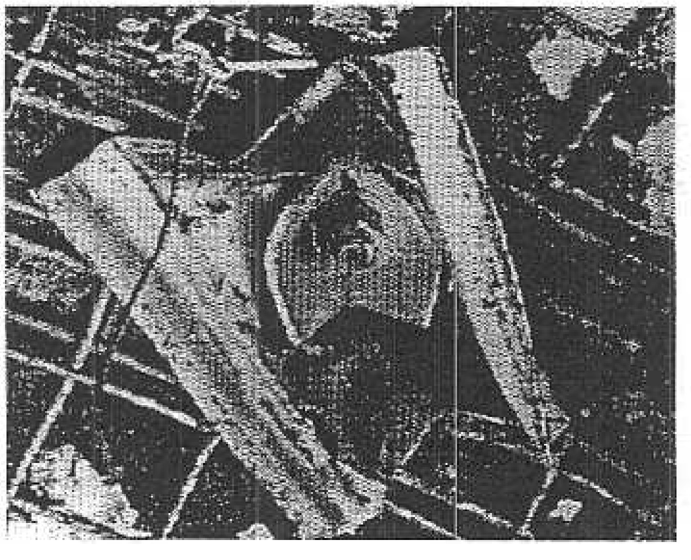

Fig. - 3 Bearing plate failed and turned inside out

Finally, the capacity of the bearing plate should not only be matched to the capacity of the rock bolt, but they should also be designed to fail progressively. They should not fail catastrophically as shown in Figs. 3 and 4.

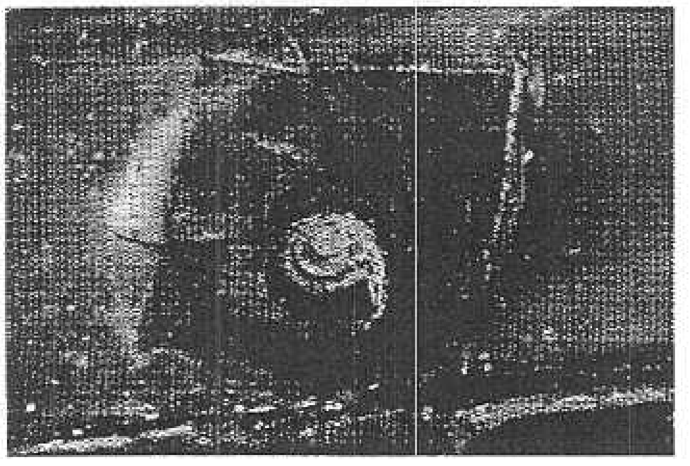

Fig. 4 – Square bearing plate has failed completely and fallen off the rock bolt.

Consequently, from both an engineering and safety point of view, it is no longer acceptable to use bearing plates which only have half the capacity of the rock bolts they are used with.

The importance of a "soft footprint"

Moreover the bearing plate should be designed not to damage mesh or straps or other support services. Square bearing plates often have sharp corners or edges, and when roof movement causes straps or mesh to be bent over this sharp corner or edge, then this can trigger strap or mesh failure. This sharp edge acts like a guillotine. This is a fundamental design flaw with most current square bearing plates. An example of a square plate cutting through a strap is shown in Figs. 5 and 6.

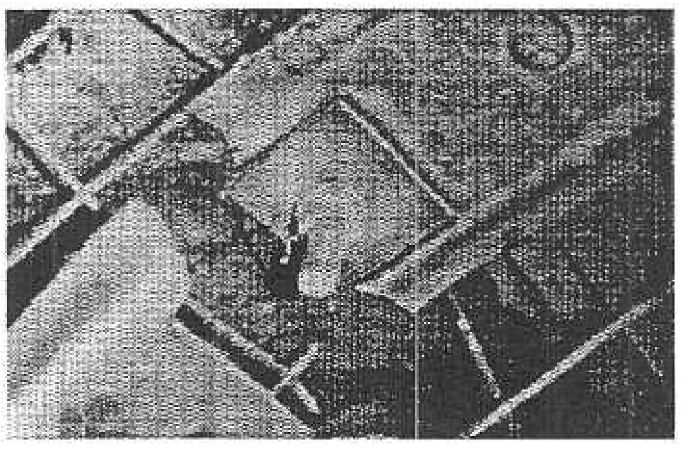

Fig. 5 - Square bearing plate has cut through the W Strap causing it to fail completely.

Fig. 5 shows that although the square bearing plate has cut through the W Strap, the plate itself is not deformed indicating that the load on the bearing plate was low when failure of the W Strap occurred. This clearly illustrates that square bearing plates with sharp edges act like a guillotine and are a bad design.

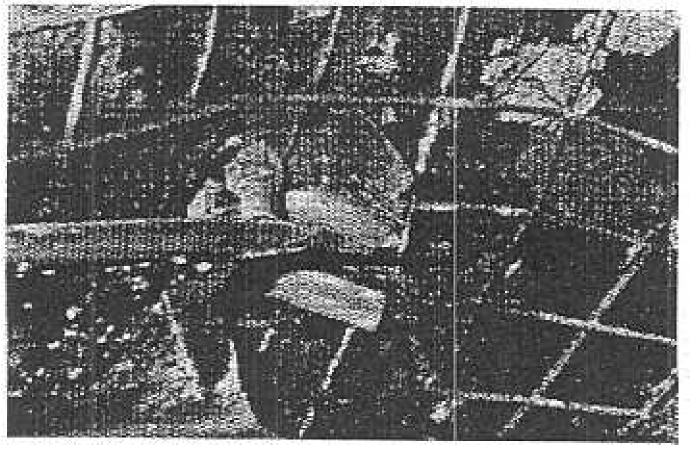

Fig. 6 - Square bearing plate has cut through and failed the W strap and then failed completely itself and fallen off the rock bolt.

Fig. 6 shows complete failure of the W Strap and the bearing plate, and in this case there is virtually no restraint to the roof at the collar of the rock bolt. The difference between Figs. 5 and 6 is that Fig. 6 has a higher collar load than Fig. 5, and has consequently caused more damage to the roof support system.

Bearing area

Furthermore, with higher and higher collar loads being generated on bolts and bearing plates due to point anchoring or long tendon support, it is important to ensure that the bearing plate can withstand these loads and that the bearing plate does not crush or punch through the rock underneath it. This often occurs where there is a weak rock in the roof (such as a coal roof). This is shown in Fig. 7.

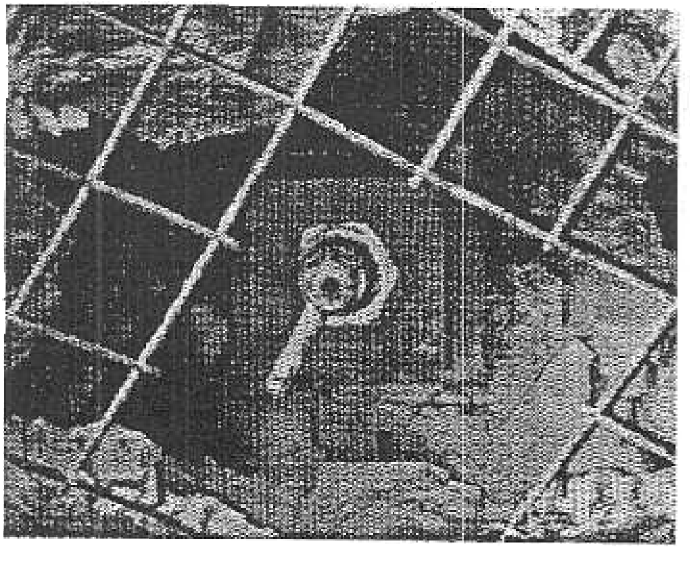

Fig. 7 - Thick, square bearing plate has punched through the immediate coal roof.

A massive, thick bearing plate used with a high strength cable bolt, is shown in Fig. 7. In this case, the bearing plate is very strong, but is of little use because this massive bearing plate will not deform along its edges and thus it can cut through anything underneath it including mesh or W Straps or even the roof itself. This is particularly important with high strength cables where high collar loads are often generated.

For example, if we take the case of a weak coal roof with an intact unconfined compressive strength (UCS) of 10MPa, this translates to a rock mass strength of only approximately 4 MPa depending upon what assumptions are made regarding the rock mass. If we further assume a stiff bearing plate of dimensions 150mm x 150mm on the end of a point anchored 60 tonne cable bolt, then it can be shown that the bearing plate could punch through the coal roof at a theoretical load on the plate of only 31 tonnes. In practice the collar load to cause the plate to punch through the roof would be less than this because the edges of the plate would cause the roof to break up around the plate (as shown in Fig. 7).

One way to avoid plates punching through the roof is to make the bearing area of the plate larger. However, there is a practical limit to the size of standard thick plates due to weight problems (maximum size typically 200mm x 200mm x 20mm). Therefore to increase the bearing area, the use of large, lightweight plates should be used in conjunction with standard plates. Also the use of mesh and straps can be used to increase the bearing area of the plate and thus reduce the contact pressure on the rock.

Mesh and W straps

W Straps and mesh help to support the rock between rock bolts, and as mentioned previously can help to increase the bearing area of the bearing plate. In the case of mesh, the initial contact area of individual wires is very small, hence the bearing pressure on the base of each wire is very high, and therefore the mesh underneath a bearing plate can be pushed into a weak roof relatively easily. This assists to lock the mesh wires in place underneath the bearing plate.
It is also important to note that failure of straps or mesh nearly always occurs at the bolt or plate contact point. In the case of straps, failure often occurs by the plate tearing into the strap (see Figs. 5 and 6). In the case of mesh, failure often occurs by the plate cutting into the wires, thus weakening them and initiating failure. Failure of straps or mesh due to steel tensile failure rarely occurs.

Large, lightweight plates

These plates have been around for many years, and are made from thin pressed or rolled steel. They are a useful adjunct to standard bearing plates because they help to spread the load over a large surface area, but at the same time they have "soft" edges which are relatively easily deformable under load. Hence they are less likely to cut or damage mesh or straps or the roof.

The performance of square bearing plates

As mentioned previously, the most common plates used in the mining industry are square domed plates used with rock bolts, and square flat plates used with cable bolts. The square domed bearing plate is a simple design which is cheap to manufacture. These plates are square which minimises steel wastage during manufacture, but also produces sharp edges and corners which can damage other support services such as mesh or straps. In addition, the thicker the standard square plate becomes, then the edges and corners also become stiffer, and are more likely to cut straps or mesh than thinner plates. Consequently, making a square plate thicker in order to make it stronger and stiffer, is self defeating because the corners and edges are more likely to damage other support services under high load conditions.

Moreover, the hemispherical washer which contacts the standard bearing plate around the domed central hole, has a bearing area which is only a tangent point, and this generates very high contact stresses as the load is increased. The plate will deform under load by the central dome being flattened, and the corners of the plate being upturned away from the roof. At ultimate failure the hemispherical washer can pull through the central hole causing complete failure, and or, the plate can split into two pieces. (see Figs. 3 and 8).

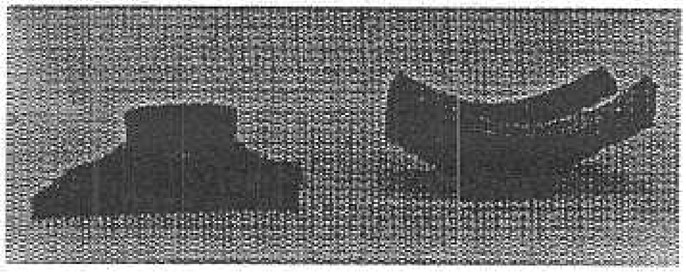

Fig. 8 - Square, domed bearing plate showing how the domed ball punches through the central hole and the corners turn up at failure

The ultimate load capacity of square, domed bearing plates depends upon the plate thickness and the grade of steel used. Approximate capacities are as follows:

- 8mm thick plates: 15-17 tonnes
- 10mm thick plates: 25-28 tonnes

However, the ultimate load capacity of a bearing plate does not indicate its performance, and other plate characteristics also need to be considered, as mentioned previously. Nevertheless the load deformation characteristics for an 8mm thick square, domed bearing plate are shown in Fig. 9.

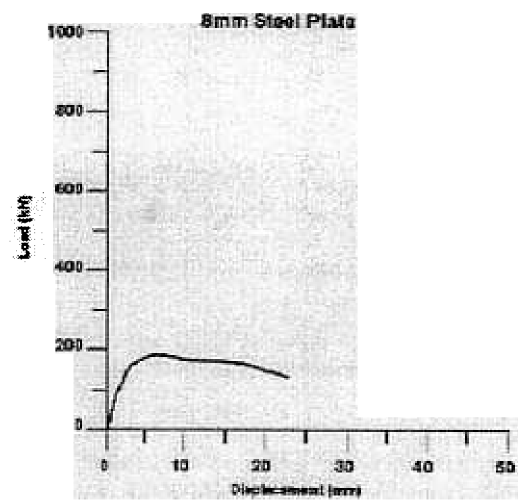

Fig. 9 - Load / deformation characteristics for an 8mm thick square, domed bearing plate

20mm thick flat bearing plates

In contrast to square domed plates, very thick square plates are too thick to press out in a conventional stamping operation and hence the plate is not "domed" to accommodate a hemispherical washer. They are simply made from flat square steel plate an a central hole is then punched or drilled through the plate to form a bearing plate. These plates are very stiff and have a high ultimate load capacity, but they are also very heavy and expensive. They not only have sharp corners and edges, but these edges are very stiff, and therefore form an excellent cutting edge for anything under the plate. (See Figs. 10 and 11).

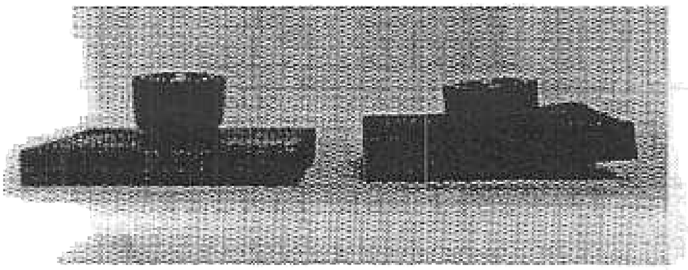

Fig. 10 - 20mm thick square bearing plate showing that there is very little deformation even up to very high loads

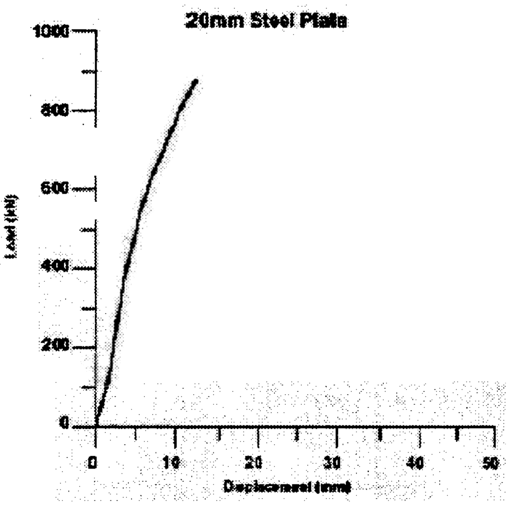

Fig. 11 - Load / deformation characteristics for an 20mm thick and square bearing plate

Very thick square bearing plates are normally used with high capacity cable bolts, and these tend to create high collar loads on the bearing plate.

Bearing plate design criteria

The preferred bearing plate design criteria should avoid the problems described above with square bearing plates. design criteria are as follows:

- the compressive strength of the bearing plate should match the tensile strength of the bolt that it is used with;
- the bearing plate should fail progressively and it should not crack or split and fail suddenly;
- the bearing plate should not damage other support services such as mesh or straps.

One bearing plate which fulfils the above design criteria is the Cup and Saucer bearing plate. It has a round design with no sharp edges or corners, and has a "soft" footprint. The footprint is initially small, but increases under load as the plate flattens out (see Fig. 12).

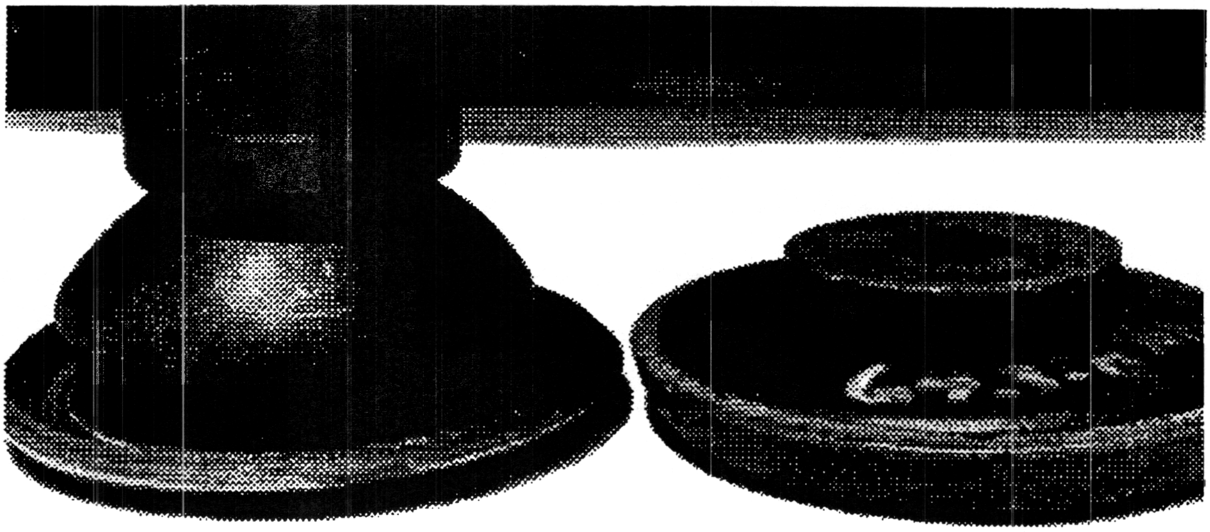

Fig. 12 - Cup and saucer bearing plate showing that the plate flattens out under high load.

The load deformation curves for the Cup and Saucer plate are shown in Fig. 13. It can be seen that the plate fails progressively, and even at extreme failure, the plate simply flattens out completely and would then begin to re-load up again. It will not fail catastrophically.

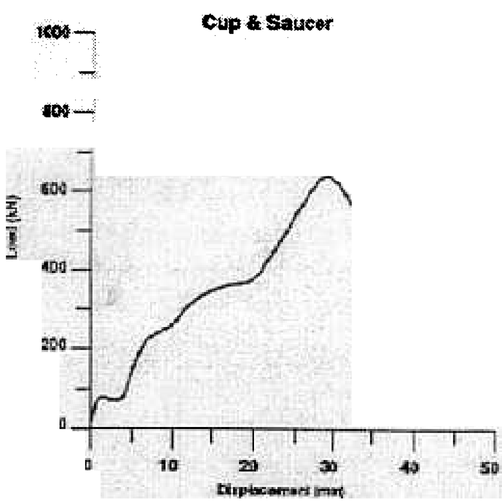

Fig. 13 - Load / deformation characteristics for a cup and saucer bearing plate.

The Cup and Saucer bearing plate also interacts very well with other ground support components, such as W Straps and mesh. In the case of W Straps, the plate sits neatly between the ridges of the strap. If movement of the roof causes the strap to bend over the edge of the plate, the "soft" edge and footprint of the plate will not cut into the strap.

In the case of mesh, the small, soft footprint of the Cup and Saucer will pinch the line wires of the mesh without cutting them, and will lock them in place (In contrast, standard square plates allow the wires to slip under the plate until the rock bolt cuts into the wires).

FUTURE TRENDS

Bearing plates are now recognised as playing an important role in ground support, and there is a wide variety of bearing plates available on the market. Bearing plates range in size from approximately 90 mm diameter to rectangular plates nearly 500mm x 400mm. They range in thickness from 1.5mm thick steel to over 20mm thick steel and even to fabricated plates with a welded structure.

Plates are made from steel, hardwood, plywood, and plastic, with these three last materials commonly being used for rib bolting where the plate is eventually mined through by the continuous miner. Some bearing plates for roof bolting now include attachments for cable slings, and others include attachments to hang services from the plate directly.
Various load indicator mechanisms are also incorporated in some plates, but at present, are all relatively inaccurate. In addition, steel mesh is now available that is specifically designed with a reinforced section to accommodate bearing plates.

The trend is clear that there are an increasing number of bearing plates available on the market, and this trend is likely to continue. Although the mining industry recognises that it must reduce its costs, it is also becoming aware that bearing plates must work effectively to be of any value. Given the very high "total installed cost" of rock bolts (approximately $100 each), bearing plates must maximise the performance of every rock bolt, and that square plates with sharp edges and corners may no longer be good viable or cost effective.

CONCLUSIONS

The actual performance of a support system will be different to that as tested in a laboratory, and the in-situ performance of any support system should always be closely monitored. Nevertheless, it can be concluded that:

1. The effectiveness of the ground support system will depend upon the interaction and performance of all components of the ground support system, including bolts; resins; straps or mesh; and bearing plates.

2. The total installed cost of rock bolts for most underground coal mines is at least $100 each. Therefore it is important that

   - all the components of the rock bolt support system work well together;

   - that they are matched components; and,

   - that they should not damage other components of the support system.

3. Bearing plates which use a domed ball to accommodate angular movement, concentrate the load around the central hole, and often fail catastrophically by the domed ball pulling through the central hole. This applies to most plates which use the domed ball principle.

4. Bearing plates which have sharp edges and corners or have serrated edges, have a greater potential to damage mesh or straps than plates without these features. In addition they can cut through W Straps with only a small collar load on the bearing plate. Very thick, square plates are even worse than thinner square plates because their edges are stiffer, and they form a very effective guillotine.

5. Even for fully grouted bolts, it cannot be guaranteed that high collar loads will be not be generated once roof movement occurs. Therefore the bearing plate capacity must be matched to the capacity of the rock bolt or cable bolt. From both an engineering and safety point of view, it is no longer acceptable to use bearing plates which only have half the capacity of the rock bolts they are used with.

6. Bearing plates should ideally have a "soft" footprint with no sharp edges or corners (ie be round), and have a capacity which is matched to the other components of the support system.

REFERENCES

Coates, D. F., Cochrane, T. S., 1971. "Rock Bolting: Research and Design Specifications" *Canadian Mining Journal* V92, No. 3, March 1971, pp37-43.

Galvin, J. Pallas, 1997. *"Status of Roof Fall Recovery Techniques"* 1st International Underground Coal Conference, Australia, June 1997, pp115-123.

Oitto, R., Zona, A., Stears, J., 1970. "How bearing plates affect roof bolt performance." *Coal Mining and Processing* V7, No. 12, Dec. 1970, pp49-52.

Norris, C., and Yearby, M., 1980. "The Choice of Support Available" Aus.I.M.M., *Colloquium on Support in Coal Mines*, pp 4-1 to 4-17.

BHPE GTLAB01.01-1996: *"Determination of Load/Deformation for Strata Reinforcement Products- Roof/ Rib Bearing Plates."*