Rock Dredging

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Summary
Rock dredging has inherently high risks even for those who are knowledgeable on the subject. Besides rock blasting, all dredging techniques are based on rock cutting, during which a tooth is pushed through rock using large forces. This process needs to be undertaken at a certain scale to create chips and be productive. Rock cutting is only economical if teeth can penetrate and cut the rock deeply enough. Therefore, rock blasting is sometimes required as a backup or it may be used as a base case.

Keywords: rock, dredging, cutting, blasting

Introduction
Rock dredging has inherently high risks. Therefore, it is essential to have an understanding of dredgers' capabilities, rock cutting physics, and rock quality and quantity. With this knowledge, it is possible to deliver rock dredging projects more successfully as the challenges are understood.

Rock Cutting
Rock cutting involves pushing a tooth through rock using a large horizontal and vertical force. Physical modelling and field measurements have determined the acting forces and have also provided insight into the physics involved.

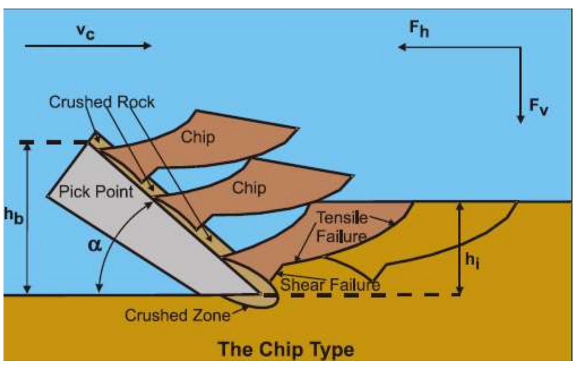

Figure 1 Pick point pushing through rock and schematised rock failure mechanism by compression (crushed zone), shear and tensile. The latter failure mechanism is relatively energy efficient and productive (Source: [1]).

When cutting rock, most of the production units are chips. Chips are created by tensile failure, which is relatively energy efficient, as most rocks behave like brittle material and fail more readily under a much lower tensile load than compression load.

If teeth can no longer be pushed deep into the rock, then energy efficient tensile failure is lost and the teeth only crush or "scrape" the rock face, mainly using inefficient compression failure and producing few chips. Therefore, to be productive, the vertical cutting force is just as important as the horizontal cutting force. Moreover, a certain scale is required to create chips. Small scale rock cutting is energy inefficient.

Unfortunately, producing chips creates high impact loads on the teeth. This makes the use of wear resistant materials, such carbide tips, impossible as these materials are too brittle. Therefore, significant teeth wear is experienced and the teeth need to be changed frequently, costing time and money.

If the rock's properties and the teeth configuration are known, then it is possible to determine the cutting forces involved. These forces determine productivity. Therefore, production estimating tools, such as in2Dredging's inhouse Estimator for (E_4) series, are based on cutting forces.

Rock Quality
The primary rock parameters are:
- Unconfined Compressive Strength (UCS)
- Rock Quality Designation (RQD)
- Brazilian Tensile Strength (BTS)
- Quartz versus carbonate content

Rock strength cannot be defined by UCS alone. At least UCS and RQD need to be known if one assumes that the UCS/BTS, or the brittle/ductile, ratio is 6 to 8. However, some ductile rock has a ratio of 1 to 3. Unfortunately, Australia is known amongst dredging professionals for its ductile rock. Fortunately, most rock is brittle and fails 6 to 8 times more energy efficiently using tensile failure.

Secondary rock parameters are:
- Point Load (PL)
- Porosity and in situ density
- Shear wave velocity
- Resistivity

PL and UCS typically have a weak correlation. Some studies have found a conversion factor of 10 to 25, but one needs to keep in mind that the PL failure mode can be very different from UCS tests.

Porosity, or in situ density, which are essentially the same, have strong correlations with UCS. Stronger rock is typically more solid and has lower porosity.

Geophysical surveys can be used to determine shear wave velocity and resistivity of rock between boreholes. Correlations can be reasonable to good. Therefore, geophysical surveys are key to quantify rock qualities.

Rock Dredgers

The following dredgers can dredge rock:

- Drilling and Blasting (D&B);
- Heavy duty Cutter Suction Dredgers (CSD);
- Large Trailer Suction Hopper Dredgers (TSHD) with ripper heads; and
- Mega Backhoe Dredgers (BHD).

D&B is a unique dredging technique as it relies on blasting instead of cutting rock, as per the dredgers. Rock blasting is not as limited by rock strength, whereas rock cutting becomes uneconomical in stronger solid rock. With D&B, however, time and costs increase as rock becomes stronger.

Furthermore, using D&B in a marine environment is quite different from using it terrestrially, which is not only reflected in the price, but also in its environmental impact, as it generates underwater pressure waves. Therefore, D&B is often excluded as an option from the start during environmental impact assessments. However, what if the rock cannot be economically dredged by cutting, is it not best to have D&B as a backup option?

CSDs cut rock by rotating the cutterhead with its cutter engine. However, the cutterhead also needs to be pushed into the rock, which can be difficult because the teeth are blunt for most of their short lifespan. Therefore, a side winch, ladder weight and spud ram are used to push the cutterhead into the rock face with great force. As the teeth become blunter CSDs become less productive due to the increase in forces required for teeth penetration. But maintaining sharp teeth means frequent delays for teeth changes. In hard solid rock, this may be as frequently as once every thirty minutes! With such frequent delays and high teeth consumption, encountering unforeseen hard solid rock can be very expensive.

A milling cutterhead has been developed to just crush rock, avoid high impact loads and successfully use brittle wear resistant materials thus extending the teeth's lifespan. This makes it possible to dredge stronger rock, if using D&B is undesirable be it at very low production rate.

The chip principle also applies to rock cutting with other dredges. TSHDs cut rock by pulling the draghead using its bollard pull, and with its deadweight helping to overcome momentary impact loads from creating chips. The draghead and under pipe need to be heavy enough to push the teeth into the rock. Depending on the weight available, one can determine the number and cutting teeth depth underneath the draghead. Only large TSHDs have enough bollard pull, and under pipe and draghead weight to rip weak to medium rock efficiently.

BHDs cut rock by breaking rock with rock buckets. The rock buckets are relatively narrow and are equipped with few teeth. The hydraulic system creates a breakout force to push the teeth through the rock. Therefore, to maximise the breakout force, it is best to minimise the boom and stick length. With stronger and more solid rock, the bucket cannot be filled from a single cutting stroke. In this scenario, BHDs can typically be equipped with dozer ripper tooth or teeth to pre-treat the rock before returning with the bucket to dredge economically.

The table below provides indicative limits for each dredging technique.

Table 1 Dredgers limitations for rock with medium RQD

Dredgers	**Unconfined Compressive Strength (UCS) [Mpa]**	
	Economical Limit	**Physical Limit**
Drilling and Blasting (D&B)	Unlimited	
Cutter Suction Dredger (CSD) with rock cutterhead	20-30	40
Cutter Suction Dredger (CSD) with milling head	N/A	60
Trailer Suction Hopper Dredger (TSHD)	5-15	20
Backhoe Dredger (BHD) with rock bucket	5-10	15
Backhoe Dredger (BHD) with ripper	10-20	25

Discussion and Conclusion

Rock could be economically dredged, depending on the type and the size of the dredger. Higher strength and solid rock may make D&B more economical.

Wear and tear on teeth is significant to extreme in hard rock. Scraping rock burns time, teeth and fuel, but produces very little rock. Rock cutting has an extremely high productivity risk as it is difficult to qualify and quantify rock. Consequently, geophysical and geotechnical investigations well funded and executed are of paramount importance.

References

[1] Miedema (2014). The Delft Sand, Clay, & Rock Cutting Model, ISBN Book: 978-94-6186-537-3.