Papers on the Lunar Settlement

Engineering 7 : Excavation

0. Introduction Any plan for lunar settlement involves the moving of large volumes of stone or rubble, for mineral extraction, to shelter habitats from cosmic radiation, impacts, and thermal variation, and for other purposes. In an environment radically different from that of Terra, this presents new problems calling for new solutions.

1. Scope of the Problem Work on earthy material involves two coordinate problems. The first is to break up the material in place. The second is to move it from its location. With loose rubble, the first step may be foregone, if it is of a convenient size to be handled, and if dimension stone is wanted the problem becomes one of dividing intact rather than breaking, but in general the description holds.

The principal materials encountered in the development of Luna will be the surface regolith, a composition of everything from fine dust to large boulders, generally cemented together into a somewhat cohesive medium, and the bedded rock presumably lying beneath the surface. In general, it is either broken rock, or the volume previously occupied by the excavatum, which is desired, rather than dimension stone. Accordingly, we may direct our discussion toward fracturing and removal of fragments.

2. Fracturing Methods Classically, terrestrial excavations are carried on by thermophysical methods or mechanical methods. The former involve the use of thermal shock to break up solid stone. The typical method is to light a fire on the rock surface, and suddenly quench it with water, producing contraction and cracking of the surface ; another, which is an important annoyance in quarrying, is winter freezing of the water retained in a newly exposed rock face, the consequent expansion breaking the stone up from within. Neither of these is at all applicable under lunar conditions. The breakup of the lunar surface materials into dust is attributed to thermal stress of the diurnal cycle, but takes far too long to act for our purposes. Thermite does not seem promising, but it might be possible to apply concentrated sunlight or heated shot to the surface, and suddenly replace the heating agent with cooled shot. Iron is suitable for this due to its reasonably high specific heat, and the ease of moving it about by non-contact electromagnetic methods.

Mechanical methods are generally divided into those using explosives and those using tools. Terrestrial practice makes extensive use of explosives, which are capable of fracturing great volumes of incompressible rock by their shock action, as well as being used with great precision. Unfortunately, explosives are uniformly organic compounds, generally containing nitrogen, and the quantities required for any substantial work would represent a truly monumental waste of volatiles. It may be possible to prepare an explosive from aluminum powder and liquid oxygen, by analogy to the composition of coal dust and liquid air used in terrestrial mining, but its behaviour is somewhat incertain. In any case, without the atmospheric cushion, blasting will result in an immense hazard from flying dust and fragments. This could be mitigated by laying a heavy cloth over the area to be blasted, to retain the ejecta.

Absent satisfactory methods of blasting, we have recourse to tools. Once again there is a difficulty. Terrestrial tooling for rock-breaking is accustomed to use steel, for its hardness, density, and abrasive properties as much as for its cheapness. While the lunar settlers may be able to spare a limited amount of carbon for making steels, the quantity will not be sufficiently large for its widespread use. Titanium, despite its strength, is only an indifferent substitute, *a fortiori* aluminum. Absent proper substitutes for steel in existing designs, we are left with the necessity of creating an entirely new type of tooling based on materials appropriate to its own characteristics.

3. Tools for Fracturing In the event, conditions suggest that many needs might be filled by stone tools, in a radical reinvention blending the distant past with the present. It should be obvious that a softer stone can be worked with a harder, if the harder can first be worked into usable form ; the brittle nature of the tools will destroy them rapidly, but the supply of material may be immense. For excavating the highland rock, the maria basalts should be sufficiently hard to do the work. Cast basalt is a mature industry, and the raw material can be collected in loose form from the regolith and cast into shape, while broken tools — more likely than worn-out ones — can be remelted.

Impact tools can be classified into two major types, the normal impact and the grazing impact. The normal type will be examined first. For the heavy work of trenching or vertical excavations, a heavy tool capable of fracturing a large mass at once is required. The tool proposed is the “leaping hammer”. This consists of two sections, probably cylindrical in form, stacked one atop the other. The bottom piece is cast from basalt and rests on the exposed surface ; it has a nub, presumably conical or hemispherical in shape, in the centre of the contact surface, and is connected to the top piece (which may be made of, e.g., thermite-process iron for greater density, as it does not require hardness) by a sliding joint. A powerful solenoid thrusts the two pieces apart, and as the bottom piece is resting on the ground, the top piece is thrown upward. The solenoid then reverses its action, drawing the two pieces together ; the ground exerts no downward force on the bottom piece, and so the momentum of the centre of mass is conserved, and both pieces rise balistically. The whole assembly then falls, and the nub on the bottom surface breaks up and forces apart the rock underneath it. The cycle then repeats. Clearly, this tool must be very large to be effective, especially under the low lunar gravity, and is hazardous to be around due to its unpredictable motion. To supply it with electric power, it could be fitted with a cable suspended from an overhead gantry, and bighted and weighted to prevent its getting tangled. The gradual motion of this gantry would tow the hammer along.

The principal grazing impact tool may be the “rotary flail”. This tool is useful for trenching, and for rounding the insides of pit or shaft excavations. It consists of several large basalt balls, suspended by cables from the rim of a large wheel. When this wheel is set rotating, the balls fly out from the centre by centrifugal force (it may require starting in the horizontal plane, even when employed vertically). Then, when the axis of the wheel is moved so that the balls touch the surface, each one in turn tends to break off a chip or flake. The degree of contact must be managed so that the balls, when recoiling from contact with the surface, do not touch the rim, which would rapidly destroy the wheel. Unlike the leaping hammer, the rotary flail may be built in many sizes, due to its independence from gravity (needed only to keep the wheel from being carried away, if the supporting structure is not otherwise physically restrained). It may also be built, by an arrangement of spokes or levers, to be adjustable in size, which could be of great use within closed excavations.

For finishing of surfaces to some degree of smoothness, as might well be required in excavations for some uses, neither of these tools is satisfactory. A kind of burnishing head seems to be called for. This device would be, perhaps, a cylindrical plug of hard, abrasive stone, with lengthwise or spiral grooves cut in its circumferential surface. This grooved face would be pressed against the surface to be finished — possibly with the addition of abrasive shot — and the surface would be worn smooth by the flats and the detritus carried away in the grooves. This tool would be wholly a finishing device, unsuitable for any large alteration of dimension or shape. For flat surfaces a similar tool grooved on the face could be applied, or a square or irregular burnisher supplied with appropriate grooves or voids could be moved in a complex pattern using an eccentric motion to scour the whole face.

For drilling gas wells, pilot holes, and the like, a conventional twist drill probably cannot be used. Besides the problem of carbon for the diamond bitts, there is the problem of waste heat. The extensive water supply used by terrestrial drillers to carry away heat and excavated material simply cannot be provided, and neither liquid oxygen nor liquid metal seems suitable. Aluminum drill string tubing would rapidly succumb to heat and abrasion, and it may be feared that titanium would do but little better. Accordingly, recourse is had to the older impact drill. This application may well require steel, although titanium bitts tipped with basalt, or some cermet, may serve. In any case, the typical impact drill uses a bundle of rods in a tube, each rod striking the surface beyond the end of the tube alternately in order to pulverize it, and the pulverized material filtering up through the empty space in the tube. Some variation on this may well be devised. There is also the shot drill, which might use a cermet in place of steel and electromagnets in place of compressed air ; the same remarks apply to shot saws and similar contrivances for working brittle materials with abrasive balls.

The channeling machine is essentially an impact drill which feeds laterally instead of horizontally, forming a trench. It is principally used in cutting up blocks of stone in quarrying. Additional methods for removing intact blocks include the “plug and feather”, using wedges in closely-spaced drilled holes along the line to be broken, similar to blasting practice ; and wire saws, abrasive cables scraping away the rock surface as their ends descend into drilled holes (the steel problem and the waste heat and abrasion problem both likely apply here, although worn-out cable can be replaced quickly). These will be of some utility for special purposes, although inapplicable to the larger projects.

4. Removal Methods Once the material is broken up, it must be carried to where it is wanted, or at least away from where it is not wanted. With the severe restrictions on manpower of the lunar settlement, backhoes and dump trucks do not seem like quite the thing to use. A more automated solution is required.

For picking up the disturbed rock, some form of bucket excavator seems called for. Even the largest dragline excavator suffers from the problem of the common backhoe, that it only has one bucket. What is needed is a machine which will operate multiple buckets, preferably unattended. To describe this machine is to think immediately of an endless chain of buckets, a sort of conveyor belt not unlike those used for grain elevators or irrigation water. In general, the buckets would be suspended on a cable running along the area to be worked, and some type of guide (presumably another set of cables and pulleys) would rotate them at the proper angles to scoop up material and to deposit it in waiting hoppers or simply in a pile, after which they would ride empty back to the starting point. It should not be missed that this system of buckets would be capable of carrying the excavatum some distance away, in a manner resembling a ski lift or aerial cable car. This would increase flexibility of the railway or other system used to carry the material to its destination.

The bucket brigade alone, however, might not be sufficient to do the job. A scoop will collect material which has been turned up and loosened, but one designed to do the loosening will be less effective as a scoop, not to mention that it will wear out from dragging, and will catch on obstacles, possibly breaking the apparatus. Accordingly, a second chain of something like moldboard plows, running alongside the buckets and turning material aside into their path, may be called for. This same method may be used, along with some sort of rakes, for excavating regolith. Drills may be furnished with screw augers for carrying up their detritus, or a system of steps relying on the reciprocation of the bitts may be practicable.

5. Conclusion While the problem of excavation is one of the principal areas of difficulty for the lunar settlement effort, it is by no means insoluble. An examination of local materials leads to the description of a set of innovative tools, furnishing the needed capabilities in unexpected ways. The devices conceived in this report may not prove to be the best, but a good solution with existing technology appears to require only the application of ingenuity to the constraints of the situation.

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