***Rivington's Building Construction Pt III Materials* (1879) London, Oxford, Cambridge. Rivingtons.**

On the face of it, herein were many myths and prejudices against pure or nearly pure lime, in favour of hydraulic materials, and against traditional craft practices born, preparing the ground for the changes that established a 'new normal' as those who were trained with this text becoming established professionals in a shifting environment of design. Great credence is given to the opinions of various engineers who had long-campaigned against craft practice and preference (particularly Henry Scott R E), with selective quotation from such as Charles Pasley which contradicted much of what they had previously thought or written. That a section might be titled 'The Evils of Fat Lime' is indicative of a clear agenda. As such, however, it presents a template of how understanding was shifting at this time – a shift that would only accelerate into the 20thC.

Chapter III

Limes, Cements,Mortar, Concrete, Plasters and Asphaltes

There are hardly any materialsused by the engineer, architect or builderon which so much depends as upon mortar and concrete.

There are differences of opinion on many points connected with the preparation and use of these materials, and there is still much prejudice existing in favour of exploded notions and of old-fashioned ideas.

These prejudices are the moredifficultto overcome, because the old-fashioned methods of preparing mortar and concretewere, as a rule, less troublesomethan those of more recent introduction….

….Setting (of a fat lime)

If a small pat be made of paste from the slaked lime and placed underwater, itwill slowlydissolve until…it entirely disappears.
In the airthe surfaceof the pat will absorb carbonic acid, which reconverts it into a carbonate of lime. This action continually decreases, and practically ceases after forming a surface crust less than half an inch thick – the interior remaining pulpy or friable, according as the situation is damp or dry, and undergoing no further change of any kind *(this is simply untrue)*.

….The solubility and want of setting power of fat lime render it unsuitable for making mortar, except for the walls of outhouses and for other similar positions. It is nevertheless frequently used for the mortar in structures of a much more imposing character…

It is, however, betterthan hydraulic limes for sanitary purposes…and is very useful for plastering and for whitewashing…

Precautions in using – fat lime requires to be mixed with a great deal of sand to prevent excessive shrinkage, but this addition does not materially injure it, as it attains no strength worth mentioning under any circumstances….

Poor Limes are those containing from 60 to 90% of carbonate of lime, together with useless inert impurities, such as sand, which have no chemical action whatever upon the lime, and therefore do not impart to it any degree of hydraulicity.
These limes slake sluggishly and imperfectly…after an interval of from a few minutes to more than an hour after they are wetted, less water is required for the process, and it is attended with less heat and increase of volumethan in the caseof fat limes…(with a lot of impurities), or if they are over-burnt, they cannot be depended upon to slake perfectly unless first reduced to a powder…the paste formed from the slaked lime is more incoherent, and shrinkslessin drying, but behaves in other respects like that made from fat lime – in fact, it is like a fat lime mortar containing a certain proportion of sand…It is in no way superior (to a fat lime) as regards setting, and should therefore only be used when no better can be had.

Hydraulic Limes are those containing, after calcination, enough quicklime to develop more or lessthe slaking action, together with sufficient of such foreign constituents as combine chemically with lime and water to confer an appreciable power of setting without drying or access of air.

Their powers of setting vary considerably. The best of the class set and attain their full strength when kept immersed in water.

They are produced by themoderate calcination of stones containing from 73 to 92 % of calcium carbonate, combined with a mixture of foreign constituentsof anature to produce hydraulicity.

(references Vicat's classification) :

Feebly hydraulic – 5 to 12% clay
Behaviour in slaking after being wetted: Pauses a few minute, then slakes with decrepitation, devt of heat, cracking and vapour
Behaviour in setting under water: Firm in 15-20 days. As hard as soap after 12 months, dissolves with difficulty.

Ordinarily Hydraulic – 15-20% clay
On slaking: shows no sign of slaking for an hour, or several hours, finally cracks all over, with slight fumes, devt of heat, but no decrepitation.
Underwater: resists the pressure of the finger in 6 or 8 days, and in 12 months as hard as soft stone.

Eminently Hydraulic – 20-30% clay

Slaking: very difficult to slake – commences after long and uncertain periods – very slight devt of heat…very often no cracking or powder produced.
Underwater: firm in 20 hours, hard in 2 to 4 days, in 6 months can be worked like a hard limestone.

Varieties of Lime in Common Use. FAT LIMES.: white chalk, marble, the Oolitic limestones, and shells, when calcined furnish the fat limes in ordinary use. A great variety of fat limes is found in England, Scotland and Ireland.

HYDRAULIC LIMES:

*Grey Chalk Lime (*called 'stone lime' in London) is of a feebly hydraulic character.
It is obtained from the lower chalk beds in the South of England, the present supplies coming from Halling, Dorking, Lewes, Petersfield, Mertsham etc.
This lime is usually of a light buff colour, and slakes very freely. When used with two parts of sand in brickwork, a good sample should sensibly resist the finger-nail at a month old.

Lias Lime varies greatly in its properties according to the locality of the beds from which it is procured, some being only moderately hydraulic, and others eminently so. The raw stone is of a dark blue colour…and the burnt lime a pale grey.
It slakes very sluggishly, and should set well in wet situations…in from one or two to several days.
This lime is sold both in lump and ground. The latter is, as a rule, the best, as the softer stones, containing more clay, are selected for grinding…
The lime is ground to nearly the same fineness as Portland cement and sold in sacks, or, for export, in casks.
Lias lime is procured chiefly from the Midland and South-western counties – the best known being that from Barrow-on-Soar, in Leicestershire; from Watchet in Somersetshire; Lyme Regis in Dorset; **Whitby, in Yorkshire**; and Rugby in Warwickshire.

The *Carboniferous Limestones* yield very valuable hydraulic limes, among which may be mentioned the Halkin Mountain limestone, from Holywell, in Flintshire; the Aberthaw lime, found near Cardiff; lime found near Berwick, etc

The Arden lime, found in this formation near Glasgow, is of an eminently hydraulic character, and has been much used for docks and other important work. It partakes rather of the character of Roman Cement and will not stand a large proportion of sand. The Milton or Hurlett lime, and the Kilbride lime, from the same neighbourhood, are of similar description.

The *Magnesian Limestones,* found in Durham, Yorkshire, Derbyshire and Notts also furnish hydraulic limes, which are sometimes of a powerful character.

In Ireland, the *calp* limestone yields a hydraulic lime, but it is very variable in character.

Artificial Hydraulic Lime may be made by moderately calcining an intimate mixture of fat lime with as much clay as will give the mixture a composition like that of a good natural hydraulic limestone, of which the product should be a successful imitation….Compact limestone, on the other hand, is more commonly burnt and slaked in the first instance, then mixed with clay and burnt a second time. Lime so treated is called 'twice-kilned' lime….The paste in either case is moulded into bricks, which are dried, calcined, and otherwise treated like ordinary lime. Artificial hydraulic limes are not much manufactured or used in this country.

CEMENTS

The cements used in building and engineering works are calcareous substances, similar in many respects to the best hydraulic limes, but possessing hydraulic properties to a far greater degree.
They may be divided into two classes- 1. Natural Cements; 2. Artificial Cements.

They are distinguished from limestones by not slaking or breaking up when mixed with water after calcination.

Cements are chiefly used for **foundations in wet places; for subaqueous work of all kinds; for important structures, where great strength is required, such as dock walls and lighthouses; also for making concrete and cement mortar. The more exposed parts of ordinary structures, such as the copings of walls, are frequently built in cement.**
Cements are also used for the walls of cesspits, the joints of drains etc; for protecting (?) the outer faces of walls and buildings from the weather; for thin walls where extra strength is required; for pointing, filleting and many other purposes.

The properties of Roman cement make it valuable for use in work to be done and set between tides, and for other purposes where quick-setting is desirable, and no great ultimate strength is required.
It is also used for external rendering or stucco, but is liable to efflorescence on the surface, which presents and unsightly appearance…

Whitby, Mulgrave's or Atkinson's cement is made from septaria of the Whitby shale beds of the Lias formations in Yorkshire. It is something like Portland cement in colour, takes slightly longer to set than Roman cement, and absorbs more moisture, but resembles it in its characteristics generally.

(Then Portland cement and many pages explaining its testing etc).

SAND AND SUBSTITUTES FOR SAND.

Sand is known as ‘argillaceous’, ‘sliceous’ or ‘calcareous’ according to its composition. It is procured from pits, shores of rivers, sea-shores, or by grinding sandstones…..

Examination of sand: Clean sand should leave no stain when rubbed between the moist hands. Salts can be detected by the taste, and the size and sharpness of the grains can be judged of by the eye.

Sunstitutes for Sand.

Burnt clay is sometimes used as a substitute for sand in mortar. It is prepared by piling moistened clay over a bonfire of coals and wood. As the clay becomes burnt and the fire breaks through, fresh layers of clay and coal, ‘breeze’ or ashes, are piled on, and the heap may be kept burning until a sufficient supply has been obtained.
The clay should be stiff. Care must be taken that it is thoroughly burnt. Raw or half-burnt pieces would certainly injure mortar.

Crushed Stone

Sand is sometimesvery economically obtained by grinding the refuse ‘spalls’ left after working the stones for walling. It is generally clean if carefully collected, but the sharpness of its grit depends upon the nature of the stone from which it is procured.

Scoria

From ironworks, Slag from furnaces, Clim]nker from brick kilns, and cinders from coal, make capital substitutes for sand **when they are quite clean and properly used. Wood cinders are too alkaline (?).**

POZZUOLANAS

Pozzuolana is a name given to several substances….including the Pozzuolana proper, also Trass, Arenes, Psammites etc.

These are clayey earths containing 80 to 90% of clay, with a little lime, and small quantities of magnesia, potash, soda, oxide of iron, or manganese.

When finely powdered in their raw state without being calcined, they may with great advantage be added to fat lime paste.

In consequence of the amount of clay they contain, they confer hydraulic properties upon the lime to a very considerable degree.

The Italian pozzuolana may with advantage be used with fat lime and sand in the following proportions:
12 pozzuolana well pulverised (*but not all powder, inevitably, without grinding)*
6 quartzose sand well washed
9 rich lime **recently slaked.**

(1 lime: 2)

Trass is…a naturally-burnt argillaceous earth, found on the sites of extinct volcanoes, chiefly near Andernach on the Rhine. It occurs in lumps of greyish colour and earthy appearance, is used in the same way as pozzuolana, and confers hydraulic properties upon fat limes.

Arenes are natural mixtures of sand and clay. They appear not to have been subjected to heat, but they confer hydraulic properties upon fat lime, probably because they contain a large proportion of soluble silica.

Psammites may be considered as 'very feeble pozzuolanas in the crude state, and acquire but a slight increase of hydraulic energy by any degree of calcination.
Even their feeble powers, however, confer upon them this advantage, that for mortars not absolutely immersed in water when green, and when there is ample time for their properties to develop themselves before submersion, they can be employed in larger proportions than any species of sand wholly inert would admit of' (Gillmore)

Disintegrated Granite, Schists and Basalt furnish sand having the same characteristics as the Psammites.

Artificial Pozzuolanas are prepared from clays of suitable composition by a slight calcination.

Pounded bricks or tiles possess the properties of pozzuolana in some degree

MORTAR

Ordinary mortar is composed of lime and sand mixed into a paste with water.

When cement is substituted for the lime, the mixture is called *Cement Mortar*.

Uses – The use of mortar in brickwork or masonry is to bind together the bricks or stones, to afford them a soft resting-place, which prevents their inequalities from bearing upon one another, and thus to cause **an equal distribution of pressure over the beds.**

It is also used in concrete as a matrix for broken stones or other bodies to be amalgamated into one solid mass; for plastering, and other purposes.

The quality of mortar depends upon the description of materials used in its manufacture, their treatment, proportions, and method of mixing….

Description of Lime or Cement to be used in Mortar – **Fat limes should only be allowed for inferior or temporary work (!!).**
On account of their being cheap and easy to manipulate, they are often used in positions for which they are entirely unfit (……)
Mortar made from fat lime is not suitable for damp situations or for thick walls. In either case it remains constantly moist; when placed in positions where it is able to dry it becomes friable, and in any case is **miserably weak (or appropriately so?)**
Even the economy of fat lime mortar is in many cases doubtful; for walls built with it are injured by frost, require constant repainting (repointing?), and perhaps before many years rebuilding (really?)

Mr Vicat says of fat limes: 'their use ought forever to be prohibited, at least in works of any importance'.
Sir Charles Pasley adds with regard to fat lime mortar that 'when wet it is a pulp or paste, and when dry it is little better than dust' (he said much more besides and advocated fat lime mortars for building in his two main treatises – both of these are taken from Henry Scott).

Evils of Fat Lime Mortar. If a pure or feebly hydraulic lime mortar is used **in massive brickwork or masonry,** it is only yhe outer edges of the joints that are affected by the carbonic acid in the air. A small portion of the exterior of the joint sets, but the mortar in the inside of the wall remains soft (this is rarely, if ever true). The result of this is that a heavy pressure is thrown upon the outer edges of the bricks or stones, and they become 'flushed', that is, chipped off. In some cases, from the same cause, the headers of brickwork are broken, so that the face of the wall becomes detached, and liable to fall away (*in which case, this would be happening everywhere, instead of only when such work is repointed with cement or other hydraulic materials at the face)*

Again, these weak mortars retain or imbibe moisture, which when it freezes, throws off the outer crust *(again, if this was so, fat lime mortars would be falling out every winter across the UK. They aren't, where they remain or are reinstated)*. Pointing is then resorted to. If this is done with the same sort of mortar, the same result ensues, and in an aggravated degree, for as the operation is repeated, the joint becomes wider. In the end it will often be found that more has been expended in patching up work done with bad mortar than would have sufficed to provide a good mortar at the first. *(No concept of compatibility here)*.

HYDRAULIC LIME OR CEMENT should, therefore, always be used in mortar for work of any importance. In subaqueous constructions it is, of course, absolutely necessary.

If there is any choice, the class of hydraulic lime will depend upon the situation and nature of the work to be done.

For ordinary buildings, not very much exposed, slightly hydraulic limes *(in which 85-90% of the lime has to carbonate!)* will suffice to form a moderately strong joint, and to withstand the weather.
For damp situations, such as foundations in moist earth, a more powerful hydraulic lime should be prepared.
For masonry underwater an eminently hydraulic lime, or cement mortar will be necessary. If the work be required to set very quickly, Roman cement, or a cement of that class, would be used; whereas, if quick setting be not necessary, but great ultimate strength is required, a heavy Portland cement should be adopted.

Cement is also generally used for copings, plinths, arches and other important parts in ordinary house-building.

Description of Sand to be Used in Mortar.

Sand is used in mortar to save expense and to prevent **excessive** shrinkage.

…with hydraulic limes and cements, the effect of sand is to weaken the mortar…When fat lime is used…the porous structure, caused by the sand (*not by the lime?)* enables the carbonic acid of the air to penetrate farther, and to act upon a larger portion of the joint.
Moreover, the particlesof fat lime adhere better to the surfaces of the grains of sand than they do to one another; therefore the sand is in two ways a source of strength in fat lime mortar. It is of the utmost importance that the sand used for mortar should be perfectly clean, free from clay or other impurities which will prevent the lime from adhering to it.

Sand for this purpose should have a sharp angular grit, the grains not being rounded, their surfaces should not be polished, but rough….
It has been found that, speaking generally, the size of the grains of sand does not influence the strength of the mortar.

….Very fine sand is objectionable for fat lime mortar, as it prevents the air from penetrating, which is necessary (?) in order that the mortar may set.

Although coarse irregular-grained sand may make the best mortar, when very thin joints are used finer sand is sometimes necessary.

Calcareous sands, on the whole, give stronger mortars than siliceous ones.

Sea-sand contains salts, which are apt, by attracting moisture, to cause permanent damp and efflorescence *(maybe, maybe not. Sea sand has a lot of calcium carbonate content – sea-shell fragments)*.

The moisture will effectually prevent a fat lime from setting, or arther drying, but would tend to increase the strength of a hydraulic lime or cement.

SUBSTITUTES FOR SAND IN MORTAR

(see above)…Smith's ashes and coal dust are used to make the *black mortar* used for pointing, slating and for some kinds of rubble masonry.

A Table of mortars made with different volumes of sand.

(breaking weight in lbs upon area of 10 inches)

Portland cement:

Neat: bricks broke first
1:1 504
1:2 433
1:3 303
1:4 420
1:5 238

Roman cement:

Neat 400
1:1 279
1:2 178
1:3 154
1:4 149
1:5 73

Blue Lias

Neat 119
1:1 80
1:2 124
1:3 29
1:4 37
1:5 42

(*Clearly, some other variables at play, but useful comparisons)*
Source: Henry Scott.)

The proportion…in mortar is generally specified thus: 1 quicklime to 2 (or more) sand.

The quantities of sand put at different times into a measure vary a little, according to the amount of moisture …but so little that practically it makes no difference.

With the lime, however, many conditions have to be fulfilled in order to make certain that the same quantity always fills the same measure.

The specific gravity of the calcined stone, the size of the lumps, the nature of the burning, the freshness of the lime…(for this reason some have proposed mixing by weight, but not as practicable).

Gives table of Scott's recommended proportions for brickwork with ordinary London stocks:

Fat Lime 1 q/l 3 sand
Feebly hydraulic limes 1 q/l: 2 ½ sand
Hydraulic limes (such as lias) 1 q/l : 2 sand
Roman cement 1: 1 or 1 ½
Atkinson's cement 1:2
Portland 1: 5
Scott's 1:4.

All for above-ground.

Quoting Scott – for hydraulic purposes and foundations 1 sand to 1 quicklime is as much as should be admitted. With cement mortar, 1:2, unless actually in contact with water, in which case, 1:1

Preparation and Mixing

SLAKING. A convenient quantity of the quicklime is measured out on to a wooden or stone floor under cover, and water enough to slake it is sprinkled over it.

The heap of lime is then covered over with the exact quantity of sand required…this keeps in the heat and moisture, and renders the slaking more rapid and thorough.

In a short time – varying according to the nature of the lime – it will be found thoroughly slaked to a dry powder.

In nearly all limes, however, there will be found overburnt refractory particles (clinker) and these **should be carefully removed by screening, especially in the case of hydraulic limes;** for if they get into the mortar and are used, they may slake at some future time, and their expansion destroy the work *(unmentioned – they are alite and will increase hydraulicity if ground with the lime before slaking, as in modern NHL production)*.

Quantity slaked and Time required.

The fat limes may be slaked in any convenient quantity, whether required for immediate use or not. Plenty of water may be used in slaking without fear of injuring them, and they will be found ready for use in two or three hours.

Hydraulic limes should be left (after being wetted and covered up) for a period varying from 12 to 48 hours, (according to hydraulicity); the greater (this is), the longer will they be in slaking. Care should be taken not to use too much water, as it absorbs the heat and checks the slaking process *(just enough to slake the free lime and not so much as to induce hydraulic set, but this is not said)*…

With strong hydraulic limes…it is advisable to slake the lime separately, and to screen out all dangerous lumps etc before adding the sand, or the safest plan is to have the lime ground before using it.

Quantity of Water Used.

The quantity of water required for slaking varies with the oureness and the freshness of the lime, and is generally between 1/3 and ½ of its bulk *(for a dry-slake)*….A recently-burnt lime requires more water than one that has been allowed to get stale.

….On extensive works a mortar-mill is universally adopted….

The heap of slaked lime covered with sand…is roughly turned over and shovelled into the revolving pan of the mortar-mill, enough water being added to bring the mixture to the consistency of **thick honey….**the mortar is shovelled out of the pan on to a 'banker' or platform…whence it is taken away by the labourers in their hods….

Before hydraulic lime is mixed in this manner it is absolutely necessary that it should first be ground to a fine powder, and with any description of lime, the smallest refractory unslaked particles should be carefully screened out….

…If a hydraulic mortar is allowed to commence to set and is then disturbed, **it is greatly injured. Care should be taken to, therefore, to mix it only so long as is required for thorough reduction and incorporation of the ingredients, and only prepare so much as can be used within a few hours.**

Mixture of Lime and Cement

Bad lime is much improved by mixing Portland cement with it. (quotes Gillmore, who was talking about natural cement gauging)…'There is no material diminution of strength until the volume of lime paste becomes nearly equal to that of the cement paste'

The following was used in the outer wall of the Albert Hall:

1 Portland cement
1 grey lime (Burham)
6 clean pit sand.

The lime was slaked for 24 hours, then mixed with sand for ten minutes. The cement was then added, and the whole ground for one minute. Such a mixture must be used at once.

(*Portland cement much less strong in this period)*

www.artuk.org.

Grout is a very thin liquid mortar sometimes poured over courses of masonry…in order that it may penetrate into empty joints left in consequence of bad workmanship *(this wasn't the reason historically)*. It may also be necessary in deep and narrow joints between large stones. It is deficient in strength and should not be used where it can be avoided.

Precautions in Using Mortar.

Fat lime mortars, unless improved by adding pozzuolana and similar substances, are so wanting in strength that any precautions in using them are of but little consequence (!!!).

In using hydraulic limes and cements it should be remembered that the presence of moisture favours the continuance of the formation of the silicates, etc…and that the setting action of mortars so composed is prematurely

stopped if they are allowed to dry too quickly. It is therefore of the utmost importance, especially in hot weather, that the bricks or stones…be thoroughly soaked, so that they cannot absorb the moisture from the mortar...

Mortar should be used as stiff as it can be spread….

CONCRETE

The materials to form concrete for ordinary work are generally mixed together in a dry state, the proportions of each being determined by custom, rule of thumb or experience.

A very common mixture consists of:

1 quicklime (*typically, lias lime)*
2 sand
5 or 6 gravel, broken stone or brick

OR

1 quicklime
7 Thames Ballast

…Mr Drake recommends

1 Portland cement: 8 gravel, for walls of buildings;
1 Portland cement: 6 gravel, for roofs, floors etc

On the Metropolitan Main Drainage Works:
1 Portland cement: 5 ½ ballast, for sewers
1 Portland cement: 8 ballast for backing walls and other work, except sewers.

Some heavy walls in Chatham Dockyard are of concrete composed as follows:
1 Portland cement: 8 slag, for the face
1 Portland cement: 12 gravel, for the backing.

At the fortification works, Cork Harbour:

1 Portland cement: 8 broken stone and sand

Underwater:

1 Portland cement: 4 to 6 broken stone and sand

In the sea forts of Copenhagen:

1 part Portland cement: 4 sand: 16 parts fragments of stone

MORTAR MILLS

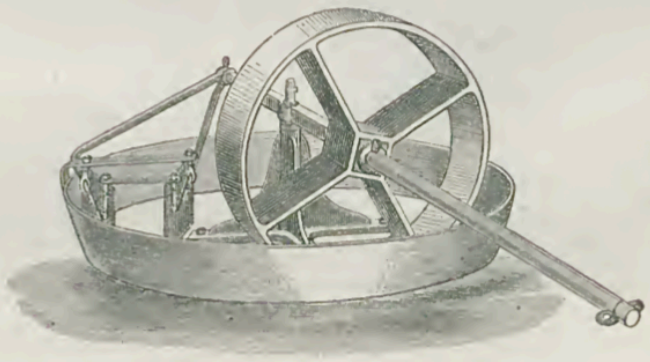

Fig. 105. *Horse Mortar-Mill.*

Horse Mortar-Mill.—A special mill, made by Messrs. Huxham and Brown of Exeter, to be worked by horse-power, is shown on Fig. 105.

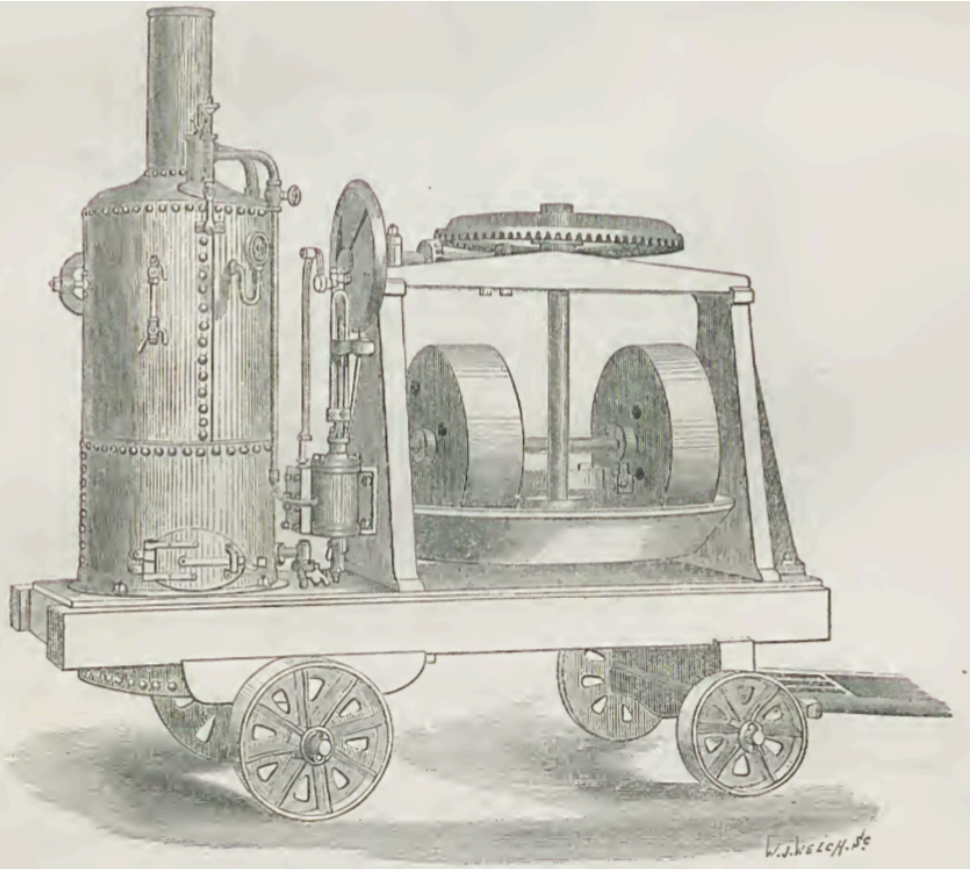

Fig. 104. *Portable Mortar-Mill.*

Such a machine will mix enough mortar to keep ten or twelve bricklayers at work.

Hand Mortar-Mill.—For still smaller works hand mortar-mills may be used of the forms shown in Fig. 106.

The ingredients of the mortar are poured into the hopper H, and find their way into the cylinder C, which contains a series of blades fixed on a central shaft, and made to revolve by means of the handle.

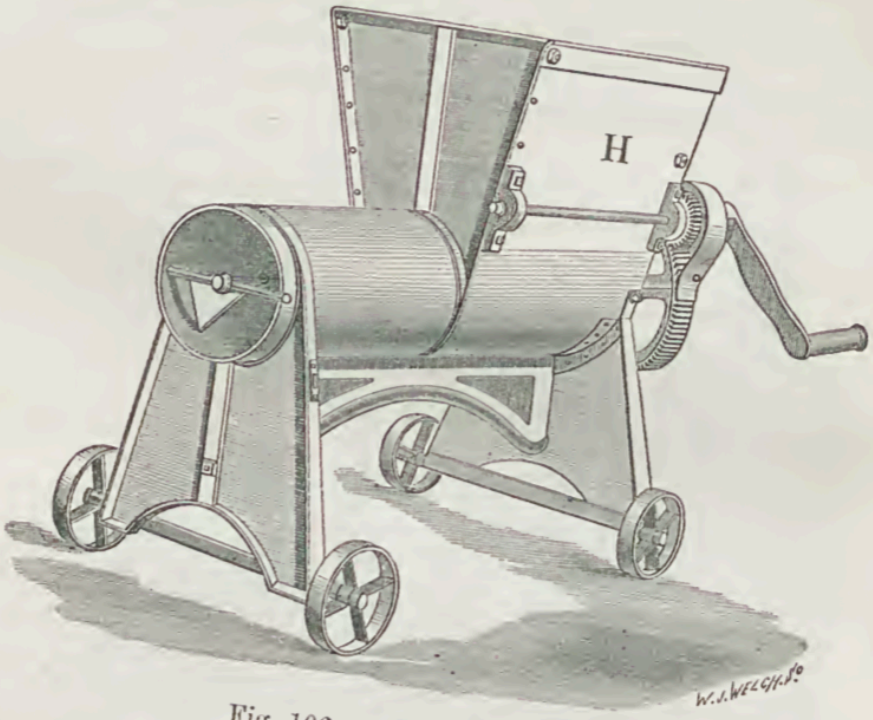

Fig. 106. *Hand Mortar-Mill.*

stated that by the aid of this machine
nd that one man