II.—*On the chief Methods of Construction used in Ancient Rome.* By J. HENRY
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Read February 24, 1887.

IN all times, from the first dawn of the historic period down to modern days, the inhabitants of Rome appear to have been a thoroughly inartistic race; but for many centuries, throughout the whole classic period, they certainly possessed an unrivalled knowledge of the best methods of construction, and were pre-eminently skilful in their use of various materials of all kinds—stone, wood, concrete, and metal. For this reason a careful examination of the many different modes of construction employed in ancient Rome is not only of interest to the student of archaeology, but may also supply many valuable lessons to the architect and engineer of modern days.

Probably no subject has had so much that is misleading written about it as this—partly because in many cases it has been treated by archaeologists who had no practical knowledge of building,—and also because the real methods of construction in ancient Rome are frequently hidden behind very deceptive modes of surface decoration.

For this reason it is necessary to warn the architectural student in Rome to trust little to existing works on the subject, however magnificently illustrated, and to use his own eyes with special care and thoughtfulness.^a

The methods of building walls in Rome may be classified thus:—

I.—*Opus quadratum*, that is solid hewn stone set either with or without mortar.

II.—*Concrete*, either unfaced or faced.

These two main classes really include the whole systems of building employed in ancient Rome.

^a The richly illustrated folio volumes of Canina are simply works of imagination; and worse than useless to the real student. Almost the same might be said of the handsome work by Choisy, *L'art de bâtir chez les Romains*.

The usual classification, which makes *opus incertum*, *opus reticulatum*, and brick, distinct methods of construction like *opus quadratum*, is wholly misleading, as they are merely used as thin facings to concrete walls.

Strange as it may sound, there is no such thing as a brick wall among the buildings of classical Rome; this will be explained below at greater length.

Opus quadratum in early times was always made of the volcanic tufa, which forms the various hills on which Rome stands. It is a soft brown stone composed of volcanic matter concreted together by age and pressure. It could be quarried almost anywhere in Rome, and was easily cut even by the bronze tools, which were used before the discovery of the art of smelting and forging iron. Fine examples of one of these prehistoric walls exist at several places round the circuit of the Palatine Hill—the so-called “Wall of Romulus”; it was about 10 feet thick, and is built of squared blocks of tufa, varying in length, but all roughly 2 Roman feet thick (*i. e.* about 1 foot $11\frac{3}{4}$ inches), and averaging 21 inches across the end. (See fig. 1.) They are set without mortar, with closely fitting beds and rather open joints. In many cases the bed is worked hollow, so as to insure the close fit of one block on to the next. Fig. 2 shows a section of this wall, which enclosed the “Roma Quadrata” of the Palatine Hill.

Fig. 1.

Existing piece of the “Wall of Romulus.”

Fig. 2.

Section of primitive wall of Roma Quadrata.

- A. Original height of wall.
- B. Upper part of cliff, now crumbled away.
- C. Cistern cut in the tufa rock.
- D. Levelled platform to receive base of wall.
- EE. Cliff made steeper by cutting.

The next stage was the introduction of the harder volcanic stone, now called *peperino*, a name given by the modern masons to two varieties, which were called *lapis Albanus* and *lapis Gabinus*, from their chief quarries (still worked) at Albano and Gabii.

Unlike the tufa this is a good "weather-stone," but it is much harder to work, and did not come into use during the earliest period. The oldest existing example of the use of *peperino* is part of the "agger-wall of Servius Tullius," where it is mixed with blocks of tufa:^a in other parts of the great circuit "Wall of the Kings" tufa only occurs.

Here again the blocks are cut into the regular 2-feet courses, but vary in length; they are commonly but not always set in alternate courses of headers and stretchers.

An interesting series of masons' marks is very visible on the back of the great agger-wall, where the surface was hidden by the *agger* or bank of earth dug out of the moat (*fossa*), which ran along the foot of the wall externally.

These marks, which average about 12 inches in height (see fig. 3), are deeply cut into the ends of the blocks: a number of examples of the same mark often occur near together suggesting that each batch of stones had its own mark.

They are mostly letters or monograms, but some few appear to be numerals. Fig. 4 shows a plan and section of the agger and wall.

Throughout the greater part of the "Wall of the Kings" no mortar is used, but one very fine piece of wall on the slope of the Aventine (in the Vigna Torlonia) has all its blocks set in a thin bed of pure lime mortar. This is not the only example that contradicts the usual statement as to the use of mortar being a late introduction in Rome; the same thin skin of lime is to be seen in the masonry of the circular *Tullianum*, a pre-historic well, which afterwards formed the lower dungeon of the "Mamertine prison," one of the oldest existing structures in Rome.

Fig. 3.

Masons' marks on walls of the Regal period.
They are 10 to 14 inches high.

^a There is no truth in the statement that these tufa blocks were split with wedges: many of them bear distinct marks of chisels from a quarter to half an inch in width. Tufa is not laminated in structure, and a wedge only shatters it to pieces.

In these cases the layer of lime is only about as thick as stout paper, and is used, not as a binding cement, but merely to make the two stone surfaces fit perfectly together.

Fig. 4.

Section of Wall and Agger of Servius.

- AA. Undisturbed earth of fossa.
- B. Earth excavated from the fossa, and heaped up to form the agger.
- C. Road at brink of fossa.
- D. Wall and buttress.
- E. Back retaining-wall of agger.
- F. Level to which the fossa was filled up, and built upon during the Empire.

The plan is given to double scale.

stretchers, like what is called in modern brickwork "English bond." Each joint at the ends of a stretcher comes exactly over the middle of a header in the course below, and with similar exactness under the middle of the header above.

In the earlier masonry the joints come at quite irregular intervals, owing to the varying lengths of the blocks used, and in the so-called "Wall of Romulus" we sometimes find one joint immediately over another, always a sign of careless or defective workmanship.

^a A wonderful example of the perfect jointing of *peperino* blocks can be seen in the recently exposed angle of the podium of the Temple of Faustina, near the bottom, where accumulations of earth have preserved the surface ever since its marble lining was torn away. Here the beds and joints are so close as to be imperceptible except with the closest examination.

^b The Roman foot was about a quarter of an inch shorter than an English foot.

In later times, towards the close of the Republic and under the Empire, this was not done, as the beds and joints were rubbed perfectly smooth, so that the junction of two blocks in well preserved examples is almost invisible.^a Thus the use of mortar in Roman stonework is a sign of early rather than of late date.

In the latter years of the Republic a very neat and regular system of masonry came into use, in which all the blocks were worked with absolute accuracy to the same size, namely, 4 Roman feet long by 2 feet^b by 2 feet. These were laid in alternate courses of headers and

The use of the harder and more valuable travertine stone (*lapis Tiburtinus*) came in very gradually; it appears to have been very rarely used before the first century B.C.^a

Fig. 5, which shows part of the wall of the Capitoline *Tabularium*, built probably in 78 B.C. is a noble example of the very regular peperino masonry just described, and also shows us the sparing way in which travertine was at first used—namely, for arches, piers, and other points of special constructional importance. Here the flat arch over the doorway is built with travertine *vousoirs*: the same stone is used for the Tuscan capitals and entablature of the open colonnade in the upper story of the *Tabularium*; all the rest of the external masonry is of peperino, while the internal walls, being safe from the action of weather, are built of the cheaper and softer local tufa. It should be observed that in the earlier buildings, where tufa alone was used, it was always coated externally with a hard stucco, which perfectly protected it against the action of weather.

The pseudo-peripteral temple of Fortuna Virilis (so-called) in the Forum Boarium affords another example of this early sparing use of travertine, which in this case is used for the free columns of the portico, and the engaged columns at the angles of the cella; the other engaged columns being built of tufa like the cella wall. (See fig. 6.) This temple is probably of late Republican date.

Later examples of the same system of using different stones occur in the outer wall of the Forum of Julius Caesar, where the keystones and springers of the arches are of travertine, the rest being of tufa, and in Vespasian's Forum Pacis,

Fig. 5.

- Example of Opus Quadratum, 78 B.C.
 Arch at foot of the Stairs of the *Tabularium*.
 The flat arch C is of travertine, the rest of peperino.
- A. Footing-course of rough stones.
 - B. Concrete foundation, exposed by the lowering of the paving when the Temple of Vespasian was built. Each block is 4 Roman feet long by 2 wide and 2 thick; a thin stratum of mortar is used.

^a Mommsen is mistaken in his assertion that travertine is employed in the barrel vault of the *Cloaca Maxima*: see Middleton, *Ancient Rome in 1885*, p. 76.

where the existing doorway (opposite the west end of the Basilica of Constantine) is wholly built of travertine, though it is in a peperino wall.

Fig. 6.
So-called Temple of Fortuna Virilis.
The black shows tufa, the shading travertine.

It should be noticed, as a valuable guide in some cases to the date of a Roman building, that when a wall is partly built of travertine the adjoining blocks of tufa or peperino are no longer worked to the regular 2-ft. courses, but range with the travertine blocks, which are never cut to regular sizes, probably to avoid waste both of labour and material in cutting up the harder and more costly stone.

Fig. 7 shows a very instructive example of the use of travertine piers, built in

Fig. 7.

Example of construction in which many materials are used.

Upper part of one of the inner radiating walls of the Colosseum.

AA. Marble seats on brick and concrete core, supported on vault made of pumice-stone concrete (C).	G. Brick-faced arch of concrete to carry floor of passage.
B. Travertine arch at end of raking vault (C).	HH. Tufa wall, Opus quadratum.
D. One of the travertine piers built in flush with the tufa wall as a point of extra strength.	JJJ. Line of steps in next bay.
E. Wall of tufa concrete faced with triangular bricks.	KK. Surface arches of brick, too shallow to be of any constructional use, and not meant for ornament, as the whole was stuccoed.
F. Travertine pier at end of radiating wall.	

flush at intervals to increase the strength of a tufa wall. This is done in all the radiating cross walls of the Colosseum.

In this case the irregular tufa courses are arranged to work in with the varying sizes of the travertine blocks; one of the facts which show that the travertine piers are not later insertions, as Mr. J. H. Parker asserted in his work on the Colosseum.

Concrete.—The most striking feature in the construction of the buildings of ancient Rome is the extensive use of concrete for the most varied purposes.

The reason why this material was so largely and so successfully used in Rome was chiefly because immense beds of pozzolana exist over a great part of the area of the Campagna. This substance when mixed with lime has the peculiar property of forming a sort of natural hydraulic cement of the very highest excellence, in strength, hardness, and durability; while its hydraulic properties, or power of setting hard, even under water, are very remarkable.

This mixture of pozzolana and lime was employed for a great variety of purposes, according as it was used alone or mixed with other materials, such as broken bricks or stone; it was equally valuable for stucco to cover walls, or for the rough concrete of foundations.

It is to this remarkable natural product that the great durability of the majority of the buildings of Imperial Rome is due.

A very interesting chapter in Vitruvius' work on *Architecture* (ii. vi) is devoted to this *pulvis puteolanus* or pozzolana, which is a volcanic product, and lies in thick strata below and around Rome, just as it was showered down from the now extinct craters in the Alban hills and elsewhere.

The best kind is a dull chocolate red in colour, and resembles a sandy earth mixed with larger lumps about the size of coarse gravel. To make wall-stucco or fine mortar it requires to be passed through a sieve.

The use of concrete dates from a very early period; it is laid in thick beds for the floors of the pre-historic houses of Tiryns and Mycenae, and we also find it used as a backing to the massive "wall of Servius" on the Aventine.

As a foundation it occurs under the Tabularium wall, as shown in fig. 5.

From the first century B.C. onwards it was the chief material used for the walls of buildings in Rome.

The materials of which it is made are often a useful indication of the date of a structure. Till the time of Julius Caesar it is usually made with broken lumps of tufa, though in some cases, under the later Republic, pieces of peperino were

also used. In all cases the other ingredients are pozzolana, and lime usually made by burning travertine (*lapis Tiburtinus*). Under the Empire, though concrete was still largely made of tufa and peperino, we find broken bricks or travertine frequently employed.

Where foundations of great strength were required below weighty structures the concrete is made with lumps of lava, the *silex* of Vitruvius and Pliny, taken from the great stream of lava which, issuing from the Alban Hills, had, during the post-tertiary period, flowed in a great stream towards the future site of Rome.

The extreme limit of this flood of lava is marked by the celebrated tomb of Caecilia Metella, which stands on its verge.

Another sort of concrete, made not for strength but for lightness, was mixed with lumps of pumice stone; this was used for arched vaults in order to diminish the weight. An example of this is shown in fig. 7. Lastly, in late times concrete was sometimes made with a large admixture of marble or porphyry. This usually marks the destruction of some older building.

Fig. 8.
Plan of the Temple of Castor.

It appears to have been some time before the Roman builders realised how great was the strength of their concrete; and it was at first used very cautiously, simply to fill up the space under the floors in temples which had solid masonry below their walls and columns.

The temple of Castor in the Forum is a striking example of this. (See fig. 8.)

Here the lofty stylobate is formed of a sort of box made of massive peperino walls; concrete was poured into this up to the level of the cella floor. A projecting spur of solid masonry was built outside the "box" to form a foundation for each column of the peristyle, and the whole of this sub-structure of peperino and concrete was finally concealed by the marble casing of the stylobate. Thus the only weight the concrete had to carry was that of the marble steps and mosaic paving.

A similar system of construction is to be

Fig. 3.

A HORIZONTAL SECTION OF A ROMAN WALL, FORMED OF CONCRETE WITH THIN FACING OF BRICK.
B VERTICAL SECTION OF THE SAME.

Fig. 4.

SECTION OF A WALL, WHICH THOUGH ONLY INCHES THICK, IS FACED WITH BRICK ON A CORE OF CONCRETE.

Fig. 5.

ELEVATION OF A ROMAN WALL AND ARCH, WITH AND WITHOUT ITS THIN FACING OF BRICK OVER THE CONCRETE.

WALL OF CAST CONCRETE, SHOWING THE TEMPORARY TIMBER SUPPORTS (FORMWORK)
A PART SHOWN WITH THE TIMBER SUPPORTS.
B PART AFTER THE REMOVAL OF THE WOOD FRAMEWORK.
C C HOLES LEFT AFTER THE WITHDRAWAL OF THE CROSS TIMBERS.

Fig. 1.

PERSPECTIVE SKETCH SHOWING THE METHOD OF CASTING OF WALLS IN CONCRETE, ONE SIDE WITH THE TIMBER; THE OTHER AFTER ITS REMOVAL.

SHOWS CEMENT.
" TUFA.
" BRICK IN ELEVATION.
" BRICK IN SECTION.

seen in the remains of the temples of Saturn, Concord, and Vespasian, at the opposite end of the Forum Romanum.

The next stage was to use concrete for independent walls; and the various methods in which it was employed may be classified thus:

I.—Concrete unfaced.

II.—Concrete faced:

(A.) With *opus incertum*; second and first centuries B.C.;

(B.) With *opus reticulatum*; first century B.C. to second century A.D.;

(C.) With brick; first century B.C. to end of Western Empire;

(D.) With so-called *opus mixtum*; third century A.D. to end of Western Empire.

The last four sub-classes are arranged in the chronological order of their introduction into use; the unfaced concrete was employed throughout all the periods for special purposes, usually for the walls of foundations and substructures below the more important stories of a building.

The manner in which walls of unfaced concrete were formed was this. (See Plate I. figs. 1 and 2.)

Upright posts 10 to 15 feet high were stuck in the ground along the line of both faces of the future wall at intervals of about 3 feet, and against these posts wooden boards 10 or 11 inches wide were nailed horizontally, overlapping each other; thus a sort of long wooden box was formed, into which the concrete was poured. The wall was in fact *cast*, and on its faces clear imprints were left both of the upright posts and the horizontal boards. It should, however, be noticed that though the main bulk of the concrete was a semi-fluid mass, yet from the regularity at which the larger pieces of stone (like the raisins in a plum cake) appear, it seems that these larger stones were thrown in separately by hand, not poured in at random as was the rest of the mixture.

The hydraulic pressure against the wooden boarding must have been heavy, and in some cases we find a regular series of holes going through the concrete wall, showing where cross-timbers were fixed as ties to keep the boarding in its place till the concrete had set. When the first tier had got sufficiently hard the wooden framework was stripped off it, and refixed as before at the top, and then a second quantity of concrete was thrown in; the whole process being repeated till the wall was formed to the required height.

In most cases the holes through the wall are absent, and the boarding must then have been supported by a series of raking shores or props.

The upright grooves on the face of the concrete wall caused by the print of the posts were often filled up, after the woodwork was removed, by the insertion of square bricks thickly set in mortar.

In foundations and walls of cellars the grooves were usually left visible.

The finest specimens in Rome of lofty and massive walls of unfaced concrete were those in the gardens of Sallust, part of the great imperial villa which originally belonged to the historian. These noble examples of Roman construction were wholly destroyed in 1884-5 to make room for rows of "jerry-built" houses, which now disfigure what was once one of the most beautiful and interesting parts of Rome. At the same time a long piece of the Servian wall was pulled down, and its massive tufa blocks broken up to make cheap rubble-work in the new speculative houses.

This horrible process of destruction was instructive, as showing how much stronger and more durable a well-made concrete wall is even than the most massive structure of masonry. The great blocks of the Servian wall were easily removed one by one, but the concrete building formed one perfectly coherent mass of great strength, and could only be destroyed in a very laborious way—like that of quarrying stone from its native bed.

This method of using concrete without any facing seems in every way so successful that one cannot help wondering why it was as a rule only used for substructures: the fact, however, remains that in almost all cases the concrete walls of the main part of each building were laboriously faced in one of the methods mentioned in the list above. As the wall-facing, whether of brick or stone, appears almost invariably to have been covered with stucco or marble slabs, the facing cannot have been added for the sake of appearance.

In one respect, and a very important one, the smooth facing was a positive disadvantage: the rough concrete forms the best possible key for the coating of stucco over it, while the smooth *opus reticulatum*, or brick, afforded but little hold to the stucco, and so the whole surface had to be roughened to give the necessary key to the stucco. This was done in a very laborious and costly way by driving large iron nails all over the wall-surface, or else by driving plugs of marble, each about 1 inch square by 2 inches long, into holes drilled into the brick facing. Very often both methods were used together—an iron nail and a marble plug being wedged into the same hole.

In some cases, as in parts of the Flavian Palace on the Palatine, a bronze wedge is used to fix each marble plug into its hole.

In this case, and in many others, this system of plugs is used not to form a key for ornamental painted stucco, but simply to afford a hold for the cement backing behind the marble slabs with which the walls were lined.

In one exceptional case, in the lower part of Hadrian's *exedra* in the Palatine Stadium, rooms decorated with painted stucco are built of the unfaced concrete, and here the stucco still adheres in its place far better than it ever did to the brick-faced walls, in spite of their marble and metal plugs.

We will now consider the different kinds of facing used for concrete walls.

(A.) *Opus incertum*.

This is the oldest kind of concrete facing. Vitruvius (ii. viii.) speaks of it and the following class thus “ *reticulatum* quo nunc (*i.e.* in the reign of Augustus) omnes utuntur, et antiquum, quod *incertum* dicitur.” In forming *opus incertum* the face of the concrete wall was studded with irregular-shaped pieces of tufa, three or four inches across, each having its outer face worked smooth and the inner part roughly pointed. Plate II. fig. 1, shows its usual appearance on the face, and also the manner in which it tails into the concrete. Examples of this, dating probably from the second century B.C., exist in the thick concrete wall at the foot of the “*Scalae Caci*” on the Palatine, in the Emporium, a series of store-chambers on the banks of the Tiber, near the Aventine, and in some houses built against the Servian wall, near the railway station, now doomed to destruction.

(B.) *Opus reticulatum*.

So called from its resemblance to the meshes of a net. (See Plate II. fig. 2.)

This is similar to *opus incertum*, except that the stones are carefully cut, so as to present a square or lozenge-shaped end, and are fitted very closely one to another. These little blocks of about 3 inches square are arranged so as to run in diagonal lines; the angles of the wall have neatly worked quoins, with the inner end pointed, so as to work in with the small lozenges. (Plate II. fig. 2.) The arches over doors and windows in walls of this class have accurately worked rectangular *voussoirs*, generally about 9 inches long by 3 or 4 inches wide. The effect of this sort of facing is very neat and pretty to look at, but its beauty appears—usually outside a building, and invariably inside—to have been concealed by stucco. The most notable examples in Rome of fine *opus reticulatum* are the “*muro torto*” built into the wall of Aurelian under the Pincian hill, the so-called “house of Maecenas” on the Esquiline, and the “house of Livia” (or “Germanicus” as it is also called) on the Palatine hill. (Plate II. fig. 2.) All these examples probably date from the time of Augustus.

Early in the first century A.D. *opus reticulatum* ceased to be used as a facing alone: the arches and angles then began to be faced with brick instead of the neat little tufa voussoirs and quoins, and surface bands of brick, about a foot deep, at intervals of 2 or 3 feet, were introduced, as for example in part of Caligula's palace on the Palatine, facing on to the Nova Via. (See Plate II. fig. 4.)

In some cases the *opus reticulatum* was only used as a sort of large panel in the middle of a brick-faced wall: e.g., in the sub-structures of the Thermae of Titus, over the golden house of Nero. Hadrian's villa near Tivoli supplies one of the latest examples of this mixed use of *opus reticulatum* and brick facing.

It should be observed that in Rome *opus reticulatum* is always made with the local tufa. A few miles from Rome, in tombs on the Via Appia, peperino and lava are both used, but only at places where these materials were close at hand.

In all cases, however, the use of *opus reticulatum* alone—that is, unmixed with bands or quoins of brick—appears to be an indication that the structure is not later than the first half-century or so of the empire.

(c.) Concrete faced with brick.

Till the first century B.C. only unburnt bricks appear to have been used in Rome, and no example of brick earlier than the time of Julius Caesar is now to be seen in the city. Strange to say, the remarks of Vitruvius on the subject of bricks for walls do not apply to any which now exist in Rome, as he only mentions rectangular bricks, while those used in existing walls are invariably triangular in shape.

It is most probable that he is referring to *lateres crudi*, sun-baked bricks, of which no example in Rome now remains, though they must once have been very common.

These un-fired bricks lasted perfectly well as long as they were covered with stucco to protect them from the rain, but when once the roof was gone, and the stucco began to fall off, the process of decay would be very rapid and complete. Recent discoveries have shown that this system of building with sun-baked bricks (like the modern Mexican *adobes*) was very common among the Greeks for many centuries: for example, the great wall round Athens, which was destroyed by Sulla, appears to have chiefly consisted of un-baked bricks, the lower part only being of stone. The same is the case in the pre-historic houses of Hissarlik, Mycenae, and Tiryns.

The most important point to notice about the use of burnt bricks in Rome is that (in walls) they are only used as a thin facing for concrete, and in no case

SHOWN	CEMENT.
SHOWN	TUFA.
SHOWN	BRICK.

Fig. 4.
ELEVATION OF CONCRETE WALL, FACED PARTLY
WITH OPUS RETICULATUM AND PARTLY WITH
BRICK. FROM THE PALACE OF CALIGULA.

Fig. 2.
DOORWAY IN THE "HOUSE OF LIVIA."
ON THE PALATINE. DATING PROBABLY
FROM THE REIGN OF AUGUSTUS.

EXAMPLE OF OPUS RETICULATUM OF THE EARLIEST SORT, WITH QUINS
OF TUFA. AT THE ANGLES A B AND C ARE SHOWN THE VARIOUS WAYS OF
JOINING THE RETICULATED WORK TO THE QUINS.

Fig. 1.
EXAMPLE OF OPUS INCERTUM
FROM THE PALATINE, NEAR THE
SCALÆ CACI. 4TH CENTURY B.C.

Fig. 5
EXAMPLE OF OPUS MIXTUM. C. 500 A.D.
FROM THEODORICI'S ADDITIONS TO THE STADIUM
ON THE PALATINE. EARLIEST EXAMPLES DATE
ABOUT 300 A.D.

Fig. 3.
HORIZONTAL SECTION, SHOWING THE
FACING OF OPUS RETICULATUM ON
THE CONCRETE CORE.

is a wall formed of solid brickwork.^a The shape of these bricks is always triangular (see Plate I. fig. 3), probably for the sake of getting a good bond into the concrete behind. So universal is this rule as to walls in Rome not being solidly built of brick, that even thin party-walls of small rooms, sometimes only 7 inches thick, are not built solid, but have an inner core of concrete faced by small brick triangles. (See Plate I. fig. 4.)

This elaborate construction for so thin a wall must have caused an extraordinary waste of labour.

It is difficult at first to realise while looking at the immense surfaces of fine brickwork among the remains of ancient Rome that all these walls are really formed of concrete, and that the brick is but a thin facing tailing into the wall an average depth of 4 or 5 inches only; yet such really is the case.

It is evident that during the formation of these walls the brick facing, which was so insignificant a part of the whole thickness of the wall, could not have supported the hydraulic pressure of the soft concrete.

It was, therefore, necessary to support the outside brick skin with a system of wooden framing like that used for the unfaced concrete. In most cases the brick facing has prevented any imprint of the framing from being left, but in some cases, as, *e.g.* in the golden house of Nero, under the *Thermae* of Titus, the channels caused by the upright posts are clearly visible. These upright grooves on the face of the wall are about 6 inches wide by 4 inches deep, and they were afterwards filled up by the insertion of little rectangular bricks so as to make a smooth, unbroken surface for the plastering.

In addition to the facing of triangular bricks, we find in most cases single courses of large tiles (*tegulae bipedales*) about 1 foot 11 inches square, introduced at regular intervals of from 3 feet to 5 feet, passing through the whole thickness of the wall (see fig. 9).

As bonding courses these tiles seem to be quite useless, because the concrete itself sets into a perfectly coherent, rock-like mass.

If anything they were points of weakness, and in fallen walls one often finds that a breakage has occurred far more readily along a course of tiles than in the mass of the concrete itself. It is, however, possible that they were useful as

^a The tops of old walls in Rome are now often protected by a covering of square bricks made to look like old ones, and this gives the wall a delusive appearance of being formed of solid brickwork.

bond for a short time after the wall was formed, as long as the concrete remained unset.

Fig. 9.

Baths of Caracalla. Section through the peristyle.

In the same way the arches which occur in the brick facing are only skin-deep, and can be of no real constructional use. That the Roman builders did not regard them as being constructionally important is shown by the fact that they often omitted the upper portion of a "relieving" arch; as, for example, at D in fig. 9, the brick surface-arch is omitted where the marble frieze came in front of it, though the lower part, which was equally hidden by a marble lining, was put in.

In these facing-arches most of the bricks used are only narrow slips, tailing into the concrete about 4 inches, but at intervals whole square tiles occur. (See Plate I. fig. 5.)

A conspicuous example of the insertion of these apparently useless arches in brick facing occurs in the walls of the Pantheon, built in 27 B.C. All round the building tiers of these arches appear, and judging from their external appearance they concentrate the weight of the walls on to certain points.

But the real fact is, that while the whole mass of the wall is of concrete nearly 20 feet thick, the brick facing, including the arches, only tails into the walls to an average depth of 5 or 6 inches, so that in reality these apparent relieving arches are of little more use (as regards the pressure) than if they were painted on the surface. The fact that the Pantheon brickwork is a mere skin on the massive concrete wall was clearly shown in 1882 during the removal of the modern houses which had been built against the back of the Pantheon. At many points deep cuttings into the walls showed the real construction to be like that of the other brick and concrete buildings in ancient Rome, namely, that the bulk of the wall was solid concrete.

The result of this system of concrete building was a far superior permanence and durability of structure than could ever have been gained by true brick-work or masonry.

In some cases a wall remains hanging (as it were) in the air when its lower part has been cut away.

A very striking example of this is to be seen in the *Thermae of Caracalla*, at a place where a brick-faced concrete wall originally rested on a marble entablature supported by two granite columns. In the sixteenth century the columns and the marble over them were removed for use in other buildings, and yet the wall above them remains hanging like a curtain from the concrete vault over head.

Another remarkable instance exists in the *basilica of Constantine*, where the column which was under the springing of part of the vault of the great hall has been removed,^a and yet an enormous mass of concrete vault remains, with no support under it, simply adhering laterally to the top of the wall.

In other cases stairs of concrete exist with none but a lateral support, as, for example, on the *Palatine hill* near the south-west angle of the "Wall of Romulus." Countless other examples can be seen which show the extraordinary advantages of this method of construction.

Concrete Vaults.—The Roman use of concrete for vaults was even more

^a This column now stands in the piazza at the east end of *S. Maria Maggiore*, forming the pedestal of a very poor statue of the Virgin.

striking and more daring than their use of it for walls, and had a very important effect upon the general forms adopted by the Roman architects under the Empire.

As the use of buttresses had not been systematised, it would have been impossible for the Romans to build and vault their enormous spans if they had used vaulting of brick or masonry, such as were built in medieval times. The Roman concrete vault was quite devoid of any lateral thrust, and carried its space with the rigidity of a metal lid. Such vaults as those over the chief halls of the great *Thermae* would at once have pushed out their supporting walls if a true arched construction had been used. But by using the form without the principle of the arch these apparently daring structures stood with perfect safety. It is true that in many cases, such as the Basilica of Constantine, and the *Thermae* of Caracalla and Diocletian, brick arches are embedded in the concrete vaults at various points, especially at the intersection of two vaults, but, just as in the brick facing of the walls these arches are merely superficial, and only tail a few inches into the mass of concrete vault, which very frequently is as much as 6 feet thick.

The elaborate drawings published by Fergusson and Choisy in their treatises on Roman construction are wholly misleading from their not recognizing the superficial character of these brick arches in the concrete vaults.

Most serious catastrophes would have occurred if the Romans had really built in the way suggested by these writers.

An example of this on a smaller scale is shown above in fig. 9, where the vault c, over the peristyle walk of Caracalla's *Thermae*, has no cross-tie at its springing, although one side simply rests on a row of marble columns, which would at once have been pushed outward if the vault above them had been a true arch.

As mentioned above, the concrete for these vaults is frequently made of the very light pumice stone; but when an upper floor rested on the vault, a bed of concrete made with hard stone, about a foot or more thick, was laid to form a level surface for the cement *nucleus* of the mosaic or marble floor: see c in fig. 9.

Wooden centering of immense size and strength must have been required to receive the mass of concrete required for the vaults of the large halls; and great mechanical skill and ingenuity were, no doubt, displayed in the construction of these enormous timber framings. Prints left on the surface of existing vaults show various methods of covering the extrados of the centering, so that the semi-

fluid concrete should not fall through : in the ambulatories of the Colosseum we see the print of wooden boards about 10 inches wide. In the sub-vaults of Constantine's basilica the impress of a sort of thatch of reeds is left.

In parts of the *Thermae* of Caracalla, and elsewhere, small square tiles were laid flat over the top of the centering ; when the centering was removed these tiles remained firmly attached to the soffit of the concrete vault, and were finally covered by a coat of ornamental stucco.

In the second and third century A.D. the Roman builders having learnt by experience how very strong a substance their concrete was, used it in some cases in the most strikingly daring way. For example, in the upper part of the palace of Severus on the Palatine, we find hollow hypocaust floors of concrete unsupported by any of the usual *pilae* or short brick pillars. These floors consist simply of a large flat slab of concrete, about 14 inches thick, which has no support except from the adherence of its edges to the walls of the room. Even in upper floors this was done, as, for example, in the house of the Vestals (see *Archaeologia*, vol. XLIX. p. 402), where a room in the first floor, over the ground floor bath-room, had its floor formed by a flat slab of concrete, with a bearing of more than 20 feet, only supported by a row of small stone corbels along its edges. In these cases the whole concrete floor is treated exactly as if it were one solid slab of stone.

Plate III. shows hypocausts in the *Thermae* of Caracalla, in which both methods of forming the *suspensurae* on hollow floors are shown—one after the older fashion with *pilae*, the other quite unsupported except at the edge.

This section also shows two methods of heating : one, employed for the hottest rooms, has not only the hot air under the floor, but also a lining of flue-tiles covering the whole surface of the wall (see DD) ; the other system was used for *tepidaria* ; in this the hot air and smoke from under the hypocaust is carried up to the roof in one circular flue-pipe deeply bedded in the concrete wall ; in which case the walls of the chamber would be cool, and the only heat supplied from the warmth of the hollow floor.

It should be noticed that these very daring methods of using concrete seem only to have been adopted by the Romans in Italy, where they could get the *pozzolana*, on which the immense coherence of the concrete depended.

In other places, such as Gaul and Britain, they had to use the weaker local materials, and here we never find the hypocausts unsupported by *pilae*, or upper floors formed of flat slabs of concrete.

To return to the brick facing ; the most valuable indications of the date of

Roman buildings is given by the size and quality of the triangular facing bricks and the thickness of the joints.

And here it may be noted that Mr. J. H. Parker's rule, that "the more courses of brick there are to a vertical foot the earlier the date of the brickwork," is wholly fallacious.

The fact is that as time went on while the bricks got thinner the joints got thicker; so a wall of the time of Severus may have the same number of courses to a foot as one of two centuries earlier.

The following table gives some typical examples of different dates, beginning with what appears to be the earliest existing specimens of brickwork in Rome:

	Date.	Average thickness of bricks.	Average thickness of mortar joints.
		Inches.	Inches.
Rostra of Julius Caesar	44 B.C.	$1\frac{1}{2}$	$\frac{1}{4}$
Pantheon of Agrippa	27 B.C.	$1\frac{1}{2}$	$\frac{3}{8}$ to $\frac{1}{2}$
Praetorian Camp of Tiberius	23 A.D.	$1\frac{1}{4}$ to $1\frac{3}{4}$	$\frac{1}{4}$ to $\frac{1}{2}$
Aqueduct of Nero	c. 62 A.D.	1 to $1\frac{1}{4}$	$\frac{3}{8}$ to $\frac{1}{2}$
Thermae of Titus	80 A.D.	} $1\frac{1}{2}$	$\frac{1}{2}$
Palace of Domitian	c. 90 A.D.		
Hadrian's Temple of Venus and Rome	c. 125 A.D.	$1\frac{1}{2}$	1
Palace of Severus	c. 200 A.D.	1	$\frac{3}{4}$
Aurelian's walls round Rome	c. 271 A.D.	$1\frac{1}{4}$ to $1\frac{3}{4}$	$1\frac{1}{4}$ to $1\frac{1}{2}$

It will thus be seen that the thickness of the mortar joints must be noted as carefully as the thickness of the bricks, in order to arrive at any safe conclusion as to date.

These examples are selected from the common kinds of brick facing, but it should be observed that in those rare cases where the brickwork was not covered by stucco or marble thinner bricks and finer joints were used.^a

As a rule the brickwork under each emperor was very uniform in appearance; but, at least in one case, namely, in part of the golden house of Nero, extraordinary varieties of brickwork occur in the same building.

^a As for example in Nero's Aqueduct for the Aqua Claudia, and in the great hemi-cycle of shops in Trajan's Forum.

TEPIDARIUM WITH HYPOCAUST ONLY.

HORIZONTAL SECTION OF WALL WITH (A) RAIN-WATER PIPE AND (B) SMOKE FLUE.

DETAILS FROM THE BATHS OF CARACALLA.

SECTION OF HYPOCAUST WITH THE FLOOR (SUSPENSURA) SUPPORTED BY BRICK PILLARS (PILÆ), AND FLUE OF CIRCULAR PIPES TO CARRY OFF THE SMOKE.

CALIDARIUM OR SUDATIO.
WITH HYPOCAUST AND FLUE-TILES UP THE WALLS.

HORIZONTAL SECTION OF WALL SHOWING THE FLUE-TILES.

DETAILS FROM THE BATHS OF SEVERUS.

CONCRETE WALL, THE UPPER PART LINED WITH BRICK AND MARBLE OVER IT.

SECTION OF HYPOCAUST WITH FLOOR UNSUPPORTED EXCEPT AT THE EDGES: 22 FT. SPAN. THE WALL LINED WITH FLUE-TILES BEHIND THE MARBLE LINING.

- SHOWS BRICK IN ELEVATION.
- " " IN SECTION.
- " STONE "
- " CEMENT "
- " MARBLE "

"TEGULÆ BESSALÆ" SET IN CLAY.

- A DOWN-PIPE FOR RAIN-WATER.
- B CIRCULAR SMOKE-FLUE.
- C C MARBLE WALL LINING AND PLINTH.
- D D FLUE-PIPES COVERING THE WHOLE WALL.
- E E IRON NAILS TO FORM A KEY FOR THE STUCCO.
- F F IRON OR BRONZE CLAMPS TO HOLD THE MARBLE WALL LINING.
- G G IRON CLAMPS TO HOLD THE FLUE-TILES, NOT ALWAYS USED.

TILES 2 FEET SQUARE.

J.H.M.

One and a-half inches is the usual limit of thickness of a brick in Rome, but in one part of Nero's palace some bricks occur as much as $2\frac{1}{2}$ inches thick, mixed up with those of the common size.

The length of bricks as they appear in a wall-face is little or no guide to date, owing to the fact that many of the sharp points of the triangles were broken off before the bricks were used—a thing very easily done in the process of loading and unloading. Thus in all Roman brickwork the visible lengths vary very much, according as more or less of the points was broken off.

(D.) Facing of *opus mixtum*. (See Plate II. fig. 5.)

This is a modern term used for a variety of concrete facing, which did not come into use till the close of the third century A.D.; the usual facing of triangular bricks, in this sort of work, is varied by bands at regular intervals of small rectangular blocks of tufa, about 10 inches long by 4 deep, and tailing 3 to 5 inches into the concrete backing.

The earliest existing example is to be seen in the outer wall of the circus of Maxentius, built about 310 A.D. by the emperor in memory of his deified son Romulus.

It also occurs in the latest alterations of the Flavian Palace, and in the Stadium on the Palatine, both probably executed c. 500 A.D. in the time of Theodoric, after whose reign, during some centuries, the destruction of existing buildings, rather than the erection of new ones, occupied the degenerate inhabitants of ancient Rome.

DESCRIPTION OF PLATE III.

Plate III. shows the details of the construction of the walls and hypocausts in the Thermae of Caracalla and the Palace of Severus.

The vertical section gives part of one of the walls formed of concrete with a facing of triangular bricks above the floor line; below the floors the concrete is unfaced, and the single courses of large tiles, which occur at regular intervals above, are omitted in the lower part of the walls.

Outside the brick facing is the lining of marble slabs (c, c), with a backing of cement; the key for which is formed by iron nails driven into the joints at irregular intervals (E, E). Long iron or bronze clamps, in some cases run with lead, fix the marble slabs in their places (F, F).

On the left-hand side is shown the section of a *tepidarium*, only warmed by the hypocaust, which, in this case, is supported by brick *pilae*.

The smoke from under the *suspensura* is carried away by a large circular clay pipe (B, B) with carefully rebated joints, embedded in the concrete wall.

A square rain-water down pipe (A) is also shown.

The section of the *suspensura*, or "hanging floor," shows the different kinds of concrete and cement of which it is formed. First, the *rudus* or rough concrete with large pieces of stone; second, the *nucleus*, a finer sort of concrete made of smaller fragments of stone or brick; and lastly, the very fine cement bedding of the mosaic *tesserae*, or the paving slabs, made of a mixture of lime and minutely pounded white marble.

On the right-hand side is shown the method of warming the hottest room, the *calidarium* or *sudatio*. In this case it happens that the *suspensura* has no *pilae* to support it. This special example is taken from the Palace of Severus, as being more perfectly preserved than any in the *Thermae* of Caracalla.

In addition to the heat given from the hollow of the hypocaust, the whole wall-surface is lined with rectangular clay pipes (D, D), through which the hot air and smoke from below made its escape. These pipes are bedded in the thick cement backing behind the marble wall lining; and some of them are firmly fixed by large T shaped iron clamps (G, G).