XI

CORRECTIONS AND REFINEMENTS

1. *Introductory*

IN writing of proportion it was found necessary to sweep away some of the mystic shroud enfolding the subject. Considering what physics, that most exact of sciences, has had to jettison in the last generation, it is astonishing that, where the visual arts are concerned, those pseudo-sciences, on which their practice is so often based, should have so long withstood the disintegrating effects of time and progress. In the case of proportion a whole chapter had to be expended on demolition.

With respect to corrections and refinements some demolition is also necessary, but in a lesser degree. In this matter, so technically subtle, the theories derived from ancient practice have remained comparatively barren of practical application. A host of designers, who have accepted without question what Vitruvius, or Scamozzi, or Pennethorne, or Penrose, or Goodyear had to say, have had little opportunity to put the matter to the test in their own work. Corrections and refinements are expensive in execution. Mediterranean sunshine and Pentellic marble might justify what could never be compassed in the pearl grey light of London and with Portland stone.

So it comes about that generation after generation of students read, apparently without amazement, that 'long lines' in architecture 'if built straight in reality would appear to sag, or drop, in the middle of their length' and slight convexity is offered as the cure. After the decay of the Greek tradition men have had to be content with fair work and square work, for the most part, and to confine their efforts in refinements to rules of thumb for the entasis of circular columns with classic capitals. For the most part, one may say; yet when Gothic art was at its summit, and particularly in England, certain refinements and corrections were general whenever they could be afforded.

Nineteenth-century discoveries of Greek practice in corrections and refinements might have led to a more practical interest in the matter, had they been accompanied by a more serious effort to relate them to the optical facts. But it must be remembered that it is only recently that most of the illusions have been even plausibly accounted for and defined. Scientific interest in the illusions was undoubtedly stimulated by the minute investigation of the corrections and refinements practised so long ago.

To-day the illusions are defined and in some cases explained. In others, there are theoretical explanations and controversial efforts to bridge the gaps of knowledge. In the chapter on The Nature of Form Vision the commonly noticeable illusions were described without accounting for them. These illusions are not diseases: their cure does not demand a knowledge of their causes, but of themselves. Corrections are an empirical business.

By a correction is meant an intentional deviation from the fair and square, resorted to with the object of making the fair-and-square-made thing look fair and square. When one speaks of a refinement one means carrying the process beyond mere correction (which is usually only effective from a fixed point of view) and making the fact of there being a correction quite obvious and, so to speak, glorying in it. That is to say, the correction becomes a subject of artistic expression.

It was remarked above that, except in the matter of columns of certain kinds, refinements are rarely practised to-day: yet most serious designers are acutely aware of unpleasant effects in their own work which, they feel, could have been mitigated by resort to corrections. By unpleasant effects one means those appearances of straight, vertical, and horizontal lines in piers, quoins, beams, and particularly in the upper elements of buildings, which feign a horrid instability; and in the case of the last-mentioned do in appearance, though not in fact, seem to overhang. Now without resorting to corrections at all, but simply by avoiding the use of certain time-honoured forms, some of these difficulties can be prevented, or greatly mitigated.

2. *Historic Development*

Before passing on to the consideration of the known means for overcoming the commoner illusions in whole, or in part, a note on the development of thought on the subject may be of interest.

Greek architecture in general and the Doric order in particular, with its simplicity and great dependence on repetition, by its very nature invited optical illusions. So whenever they could afford it the Greeks attempted to deal with them and often succeeded very well. This empirical science was not fostered by the conditions under which the Romans did their building, although they appear to have been well aware of the Greek effort in this direction. Ictinus, the architect of the Parthenon, committed his practice to writing, but the book has been lost. Vitruvius may have read it or a subsequent restatement of the problems involved. His own contribution does not amount to more than a corroboration of the fact that the problem was recognized in the first century A.D. The Italians of the Renaissance give Vitruvius credit for knowing all about it, but Peruzzi, by far the most Greek-minded of all the Italians, does not appear to have either preached, or practised, the corrections.

The loss of Bramante's treatise, which probably reduced his own practice to a systematic basis, is much to be deplored, but there is no reason to suppose that he dealt with corrections; proportion would interest him more. The great exponents of versatility—Alberti, Michelangelo, and Leonardo da Vinci—do not seem to have been seriously exercised over the perverse behaviour of long straight lines in buildings; and it would hardly have occurred to any of them not to build a corner column plumb on its centre. Considering the exquisite delicacy of the architecture of the Italian renaissance it may seem odd that so little thought was given to the matter. But it may be suggested that the Italians succeeded, above all others, in producing an architecture which did not require correcting. So with Wren, Chambers, Perrault, and Gabriel; they were one and all adroit in not provoking distorting illusions in their work. Just how far this is attributable to good luck and how far to good management it is difficult to say, but the suggestion is hazarded that there was little or no luck about it.

Between 1832 and 1838 Pennethorne made a study of the Vitruvian canon of additions and diminutions on the spot, in Greece, the Erechtheion being the subject of his special study. It was not, however, till 1878 that his results were published. In 1847 Penrose made his researches on the corrections of the Parthenon and the Propylaea and his work has been the classic on the subject ever since.

The analytic study of Gothic architecture, which was the chief accomplishment of architectural scholarship in England from 1825 to 1900, was well advanced at the time of Penrose's studies in Athens. It appears, however, that it was not till some time after his researches that the measurers of English parish churches began to observe variations of form which could only be accounted for as correctional. It is interesting to note that two devoted students of English medieval art, G. F. Bodley and E. S. Prior, notwithstanding the diversity in the complexion of their thought, have both recognized that certain corrections were current practice in western Europe in the fourteenth century.

This aspect of the subject has been somewhat obscured by controversies centring on the enthusiastic championing of the case for medieval refinements by Mr. Goodyear of the Brooklyn Museum. Notwithstanding some loose thinking and imperfect observation, resulting in claims for intentional variation from the normal form where the variation could be explained on other grounds, it is well established that in thirteenth-century practice in western Europe to some extent, and in fourteenth-century practice more markedly, refinements and corrections of several kinds were quite general. The Black Death, which had such devastating effect on economic conditions, brought building to a standstill and this tradition died. In the later Gothic architecture there is no trace of corrections. But, having in consideration the character of this architecture—its brusqueness in England, its exuberance on the Continent—it is difficult to see that there could have been any great occasion or necessity for resort to corrections. Was it the knowledge of them or the need of them that had passed? Perhaps the knowledge with the need.

The advocacy for recognition of the facts as to corrections in Greek and Gothic art does not necessarily enlighten us as to how to direct our own talents in the matter. Observation of the buildings we know and frequent, with a knowledge of the several commoner illusions at the back of our minds, must be relied on in forming our judgements as to what is worth correcting and what is not and, most important of all, as to how not to provoke the need of corrections.

Some of the more usual corrections will now be described in the order in which the illusions they discount were touched upon in a former chapter.

3. *Top-heaviness*

The upper part of any figure appears larger in every way than the lower half. This is particularly noticeable in the case of tall cylinders and parallelepipeds. The effect is strong enough to overcome the vertical perspective diminution in the case of cylindrical columns 30 ft. high seen from 40 ft. away with five-sixths of the column above the eye. S's and 8's, as has been noted, are usually

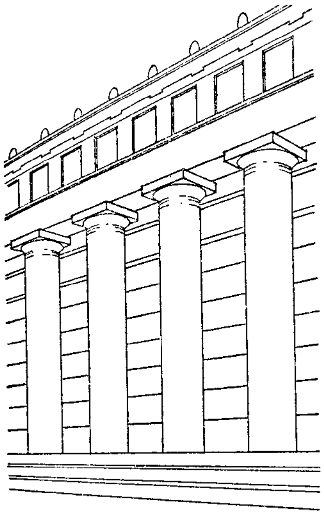

FIG. 53.

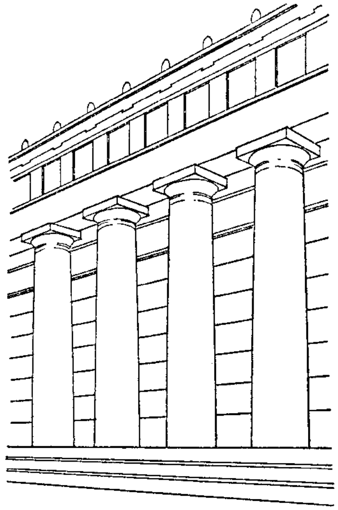

FIG. 54.

FIG. 53. The illusion of increased size in the upper portions of figures exemplified by a Doric colonnade with cylindrical drums.

FIG. 54. The same colonnade as in Fig. 53 with the columns tapered more than enough to neutralize the illusion.

formed with the upper loops of less radius than the lower ones to discount this illusion. Classic columns without a taper look top-heavy on this account, and not, as is sometimes supposed, just because we are so well accustomed to see them tapered. Even a drawing of a colonnade set out in perspective with parallel vertical lines to indicate the outlines of the shafts will show this effect.

Now by suitably tapering the shafts so that they become parts of cones instead of cylinders this effect can be corrected as for any given point of view, or distance from the eye. But such a correction will be either inadequate or over-adequate for all other distances. Taper and batter, when resorted to, are therefore usually made fully adequate so as to tell even at a fairly close view. At a very close view of a cylindrical shaft extending far above the eye the perspective diminution becomes acute enough to take charge, so to speak, and the illusion is obliterated, or seems to be, which is as good in the case of something disconcerting that was never really there.

Italian balusters, with a central neck and the mouldings above the neck repeated below it in reverse, are apt to provoke this illusion of top-heaviness very noticeably. The neck should be set out about one-twentieth of the height above the midway point, and the baluster section should be worked out with a taper so that the lower diameter is larger than the upper diameter at all corresponding reversed points. This correction is interesting as being one of the few, other than those for the column, practised by renaissance architects.

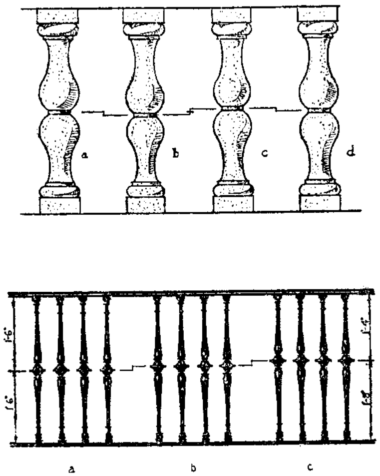

FIG. 55. Stone balustrade: balusters *a* and *d* are symmetrical above and below their centres; *c* is corrected; *b* is the same as *c*, but inverted.

Iron railing; the group of balusters at *a* are symmetrical top and bottom; those at *b* are corrected; those at *c* are still smaller above than below, yet look as if they were those at *a* inverted.

Curiously enough, in the case of the shafts and piers carrying arcades in medieval architecture, the upward enlargement illusion is not felt noticeably, and is therefore never corrected. The reason is that the wall-faces and the arch intrados overhang the face of the shaft substantially; the strongly moulded cap, acting as a transition member, gives further emphasis to this fact. The illusion of exaggerated contrast, thus arising, neutralizes the illusion of top-heaviness. The nave arcade at Snettisham in Norfolk is a good example of this.

4. *Subdivided Space*

The illusion of subdivided space has already been referred to as being strong enough to upset the judgement as to size and

proportion in the case of figures similar in either of these respects. Horizontal, or vertical, subdivision into only two or three parts provokes the illusion of greater length in the *direction of the subdivision* lines. Thus when we place a strong belt course at the first floor level of a two- or three-story building we lengthen it in appearance. But multiple subdivision into from five to a dozen parts has the contrary effect by provoking the illusion of increased height or breadth in a direction *perpendicular* to that of the *subdivision.* A basement wall with six or eight courses rusticated on the beds will look taller than one in plain ashlar, but not so tall as one of equal height divided into ten or a dozen such courses. So with a colonnade of given height and given width centre to centre of the outer columns. If set out with six columns the thing as a whole will look wider than if set out with four, and not so wide as if set out with eight. 'The thing as a whole' will look wider, but, if the attention is only concentrated on two or three of the columns and the spaces between them, the wider set columns will appear slimmer than those closer set, by contrast with the wider spaces between.

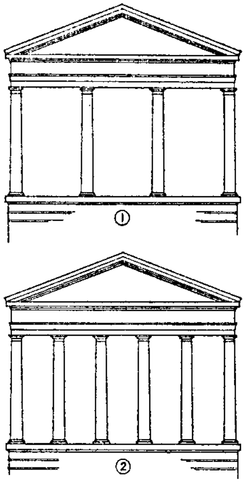

FIG. 56.
1. A pediment borne by four columns. 2. The same pediment borne on six columns.

Much may depend in such problems on the emphasis of the subdividing lines and on the proportions of the subdivided area. The flutes of columns do make the shafts appear thicker, especially at so close a view that only a small portion of the shaft is seen, but they also make the column, when seen as a whole, seem taller than an otherwise similar unfluted one. What is true of a closely subdivided square is not true of a closely subdivided figure from 7 to 10 times as long as it is broad. Great piers, like those at the crossing of Lincoln Cathedral, with their strongly marked multiple subdivision into shafts appear thickened, but the slender piers at Snettisham, divided into only four lobes on plan, not more than three of which can be seen at one time, appear the more slender on account of the limited subdivision. The triglyph looks the taller in virtue of the mildly marked subdivision in three, but put two triglyphs together and contrast them with an equal space and see what happens.

As composition consists very largely in arranging the subdivision of space, one might pursue the matter farther and deal with fenestration, voids and solids, and so on; but perhaps enough has been said to elucidate the principles on which the illusion in question may be disposed of when required, or on occasion used to advantage.

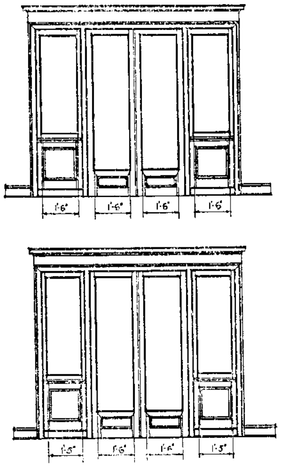

FIG. 57. Correction in the width of window panes.

5. *Contrast*

Objects differ from one another in actual size, or in the proportions that can be observed between their several parts, or in both. A big thing and a small thing seen together, provided there is some common characteristic of form, enhance each other's characteristics of size, but without illusion. Yet when difference of size is negligible or ignored as an element of comparison, a tall thing placed in relation to a broad thing will look the taller and the broad thing the broader. If the tall thing is not very tall and the broad thing not very broad, the illusion of their difference will be all the greater, not all the less.

So, if we have a pair of glazed folding doors, with glass panels 1 ft. 6 in. × 5 ft. 6 in., set between two lights, in the same frame, with glass panels 1 ft. 6 in. × 4 ft., the taller panels will look about 1 in. narrower than the shorter panels. That is to say, they should be made 1 in. wider to look the same, or, better still, 2 in. wider so that there may be no doubt about it, or question as to whether the folding doors are subordinate to the side lights, or vice versa.

In the case of a bay window made up, let us say, of two lights to the front and single lights on the sides a similar correction is often made, but the reason is not quite the same. In this case the side light is apt to look broader than the two centre lights, apart from the point of view, because the centre lights are closely related to the broad unit composed of the pair, which makes them look taller in proportion and therefore narrower than they really are.

Just as in the case of colours not far apart on the spectral circle, where there is an illusion of greater difference than there actually is, so also in the case of figures not very different in proportion there is an illusion of greater difference than there actually is; but the analogy ends with the effect, for the causes are radically different. Colour contrast illusion would seem to be largely an optical phenomenon, whereas form contrast is largely, if not wholly, cerebral.

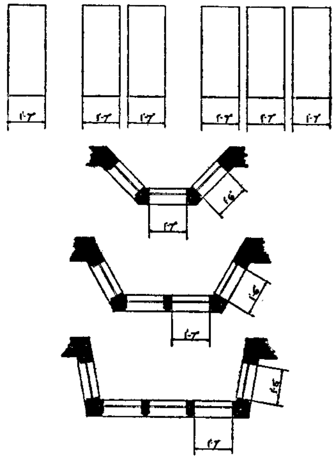

FIG. 58. Corrections for bay window side-lights.

In considering corrections for the subdivided space illusion the tendency has been to regard the phenomenon as affecting apparent size in the first place and apparent proportion secondarily. The illusion of enhanced contrast seems to affect proportion primarily and size secondarily. Whatever is the case, the results are matters with which those concerned in the visual arts do well to reckon. If, for good and sufficient reasons, the designer is aiming at height, or at breadth, or at a similarity in either of these respects, he cannot afford to allow a controllable illusion to discount his efforts. He can raise, or bring down, the ceiling of a room by placing a dado rail low or high, or by allocating less or more space to a frieze and cornice; and the same with an exterior wall-head. In the design of tall buildings it is a mistake to suppose that multiple vertical subdivision will necessarily give an increased sense of height for the whole. That must depend on whether the tallness and narrowness of the parts can make the dominant appeal, distracting attention from the equal tallness with greater width of the block of building as a whole.

In the later medieval towers of France and England the strong horizontal water-tables and string-courses have more to do with the impression of height than is generally supposed. They establish broad, subordinate rectangles which contrast illusively with the main vertical rectangles. The interrelated play of scale and proportion has its part in these compositions, but resort to illusions of subdivision and contrast may be more than suspected. How far this might be conscious and calculated, and how far the intuitive grasp of the possibilities of a well-developed tradition, it is difficult to say, nor need it concern us.[1]

If the reader will first sketch, and then measure up, and then photograph any one of a hundred Picardy church towers he will soon convince himself that, whether intentional or not, all the rectangles are supporting one another directly, or indirectly, in a conspiracy to minimize girth and exaggerate height. With a shock he might find that the visual image of the tower occupies 10° horizontally and only 30° vertically. Had he turned his back on the tower and drawn it from memory he might easily have given his impression by a sketch in the ratio of 1 to 5 without disgracing himself as a draughtsman.

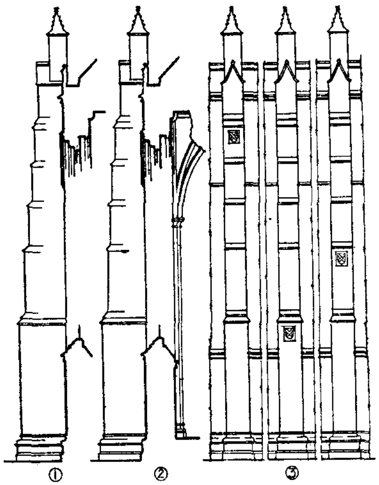

FIG. 59.
1. Buttress with vertical faces. 2. The same with vertical faces modified beyond mere correction. 3. Effect of placing an interrupting spot at various points on a buttress.

6. *Confluence*

The illusion of confluence is that by which spaces between given points tend to be misjudged by the occurrence of figures, with centres of interest of their own, in some relation to the given points. Lines of equal length with attached figures having centres of interest beyond their ends look longer; if within the ends they look shorter. What may be called the effective length of a Corinthian column extends from the centre of the cap to the centre of the base. A column of the same total height and diameter with a shallow Tuscan cap and no base will look considerably taller. The places selected for interesting decorative medallions, or even plain openings, thus have a considerable influence on the apprehended distances related to them, and consequently on the proportional relations of elements in their vicinity.

For example, suppose a buttress with six offsets and that a coat

[1] See Figs. 38 and 40 above.

of arms is to be placed on the face below one of them. The buttress, let us say, has a pinnacle of some elaboration and a heavily moulded base. One may exercise one's ingenuity in finding where to place the shield, first of all so as to make the buttress look as tall as possible, then to make it look as short as possible, and lastly to change its apparent height as little as possible. One cannot put the coat of arms at any offset without affecting the apparent height to some degree. A question of this kind is rarely a matter of indifference in the design; and to the designer it may be of high importance.

7. *Over-estimate of Angles*

The natural tendency for the retinal images of acute angles to provoke an exaggerated impression of the measure of the angle (increasing relatively to the angle as the angle diminishes) is of greater importance than the illusions so far dealt with. In one form or another this illusion is ubiquitous and incessant, as long as our eyes are open and there is light to see by. It will be remembered that parallel lines crossing another line obliquely result in an apparent displacement of the crossed line; also that when a pencil or group of lines meeting in a point is traversed by a line (making a series of successively more acute angles with the lines of the pencil) the traversing line appears to be bent, if straight; if of suitable curvature, it appears straight. So when actually parallel lines are seen in perspective, as lines vanishing to a point, they distort lines which traverse them.

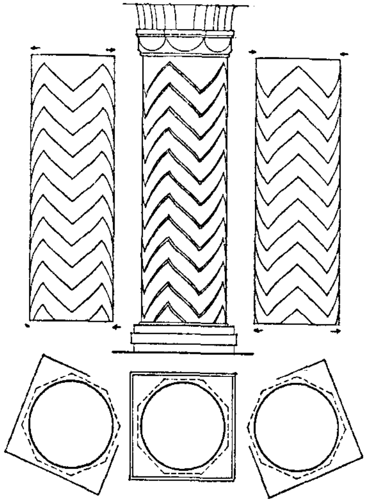

FIG. 60. The Durham piers not only look as if tapered to the top, and to the base, in different views, but appear to lean this way and that as the point of view is changed.

Consider the zigzag decorations on the shafts of the main piers at Durham. We have here a device which renders the cylindrical shafts conical (pointed upwards) in one view, conical (pointed downwards) in another, and parallel sided but leaning to right or left in intermediate views. The jester who worked that trick had a sense of humour. Let us hope they forgave his devilry, for he lived at a time which knew the use of boiling oil and the rack. A correction could be instituted for any one of the three views, but not for any two, or all, and if instituted for one the effect on the others would be deplorable.

Let us turn to a more serious example in the case of the effect of buttress offsets[1] on the vertical faces between them. Here the top of each face seems pushed out and the foot drawn in by this illusion; the line of the re-entrant angle between the buttress and the wall tends to be set back at the top and drawn out at the foot by its relations with the face quoins which seem to make acute angles with it, though they actually do no such thing. The correction for the buttress faces is to batter them, preferably with an entasis, as was done at the Wayside Chapel at Houghton-le-Dale in Norfolk. The correction for the re-entrant angle line is by the use of string-courses to destroy the influence of the faces and so keep things where they really are.

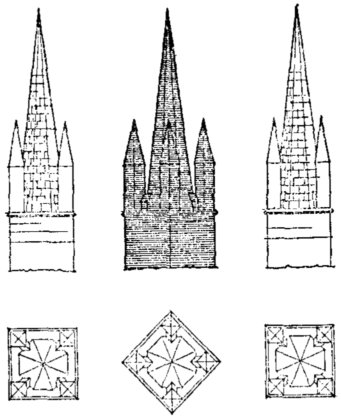

FIG. 61. The correction for corner pinnacles.

Octagonal spires set on square towers always provoke illusions of the class under discussion. The lines of junction between the faces of the cone form a pencil and the quoins of the tower constitute vertical lines. These sets of lines may not actually cross each other, but they are affected as if they did, the quoin lines being apparently thrown out of plumb at the top. The effect in the pencil lines is similar, but not so noticeable, as sensitiveness to verticality is not brought into play. Corner pinnacles and the faces of lucarnes are affected even more noticeably than the tower quoins, because their vertical outlines actually traverse the pencil of lines. Lucarne faces are therefore battered in the work of the best Gothic period; as also in the later work of the Gothic revival after the artifice had been rediscovered. Otherwise they appear to hang outward and suggest instability. When there are strong cornice features and

[1] See Fig. 59 above.

nearby buttress offsets and the spire comes down well within the parapet, corner pinnacles are not affected appreciably.

In the diagonal view of the King's Weigh-house Chapel spire in London, especially when viewed in a haze causing a silhouette effect without detail, the corner pinnacles appear to be thrown out to an alarming degree. If such features mean anything, they signify stable counterweights over the squinches carrying the diagonal

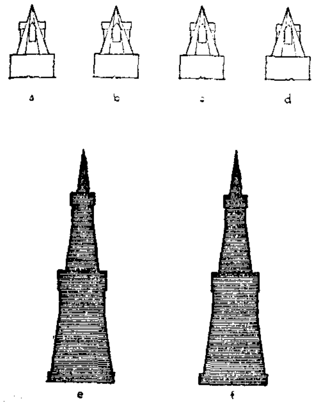

FIG. 62.

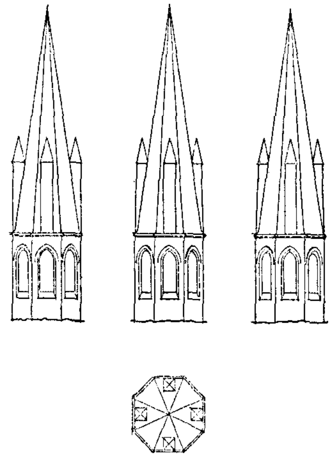

FIG. 63.

FIG. 62. The correction for lucarnes (as at Heckington, Lincolnshire). *a.* Vertical faces appear to hang outwards. *b.* Exaggeration of impression given in *a.* *c.* Corrected by battering. *d.* Refinement by over-correction. *e.* Lucarne faces vertical. *f.* Lucarne faces battered for correction.

FIG. 63. Correction for lucarne pinnacles on octagonal spire and tower.

faces of the spire, and resort to artifice, to make their stability unquestionably apparent, as well as real, is more than justified. When lucarne and pinnacle forms are combined, as is so often the case in early French Gothic spires, the illusion appears in its most pronounced form.

The voussoired flat arch is an interesting case. It is generally agreed that the soffit seems to droop in the centre. Here the back, or extrados, and the soffit, or intrados, are a pair of parallel lines met by a series of radiating lines—a part of a pencil of lines. Why do the lines intersecting the pencil not behave as they should and curve if anything upwards to the centre? In the first place, the pencil is not sufficiently extended to introduce acute angles: its effect is there, but weakly, and is more than overcome by other factors present. Of these the most important is the fact that from the key outwards the voussoir joints become successively longer, provoking contrast with the actual depth of the arch, which is constant. The distance between the parallel lines therefore seems less at the ends. This contrast does not make the centre of the soffit seem to hang down, but it makes the two ends of the soffit seem to curve up. There is also the question of the outline of the arch as a whole. The two raking abutment lines combine with the soffit line to form a figure extending from point to point at the ends of the head. This merged group of lines would by confluence tend to give a slight sag to the soffit line even if there were no voussoir joints present or visible.

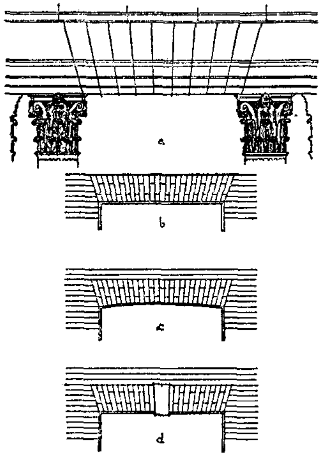

FIG. 64. In the voussoired flat arch the effect is contrary to what might be expected; see text.

The correction is of course the usual slight camber, but it is better to make this sufficiently accentuated so that it will show as a camber; but if this is overdone the back of the arch may show as a drooping line. A keystone with a soffit below the soffit of the rest of the arch (which a keystone from its nature as a wedge should have) is no remedy, but only accentuates the apparent sag merging with the figure above alluded to. Flat arches are not good structural forms and are very apt to have a real sag. So much so that any one familiar with arches rather expects to see it. In vision, expectation has a great deal to do with what one actually sees—interprets as there from the visual local signs.

A façade of a building with battered walls and all the usually vertical lines of openings and other features set out to meet at the point where the quoins would intersect would look higher than it actually was from a central view, because one would assume that all was plumb and parallel, and infer that everything about it was taller than it was in order to provoke so much diminution. A partial application of this principle is occasionally used in Italian

architecture. For example, in the New Sacristy of San Lorenzo at Florence there are windows with raking jambs, adorned with architrave frames and segmental pediments, set in the lunettes which fill the arches between the pendentives below the drum of the vault. These are designed to provoke the illusion (which they do when seen from below) that they and the spaces in which they occur are taller than they really are. The inclination of the inner colonnade below the drum of St. Paul's is another case in point. Here foreshortening is discounted. If the later Renaissance architects used very few true corrections, they did not hesitate to provoke illusions involving perspective in the interest of height.

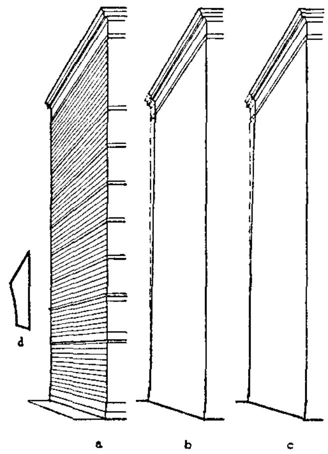

FIG. 65.

a. The illusion of a winding surface and outbending quoin in a coursed wall. *b*. Correction by batter would not get rid of the out-bend. *c*. Entasis and batter would cure the out-bend as for a given point of view. *d*. Exaggerated figure to illustrate the illusion in *a*.

A common practice for giving apparent height to a roof is to diminish the gauge of the slate gradually from eaves to ridge. A gradual diminution of the height, or proportional height, of window panes in the successive stories of a building has a similar effect with respect to the wall. This is sometimes also accompanied by a diminution in the height of courses of the masonry.

The effect of horizontal lines such as window-heads, sills, string-courses, and the bed lines of brick or masonry (especially when emphasized by rustication) is very different in the case of a building viewed from the ground, in perspective, from what it is in an elevation drawing of the building. When seen in perspective these horizontal lines always form parts of a pencil of lines intersected by vertical lines, expected parallel as such, though actually vanishing to a point above the beholder's head. Thus the far quoins of the building appear to curve outwards towards the top, and the upper wall surface takes on a winding appearance. The correction for this is batter with entasis. In any given case, from any given point of view, the necessary correction can be made empirically; but of course this correction will not hold good for the view from another position. Besides, when we give batter (or batter and entasis) to one line, such as the quoin, we only set all the other lines that remain vertical to leaning out more pronouncedly. The application of batter and entasis in such cases is not therefore practicable.

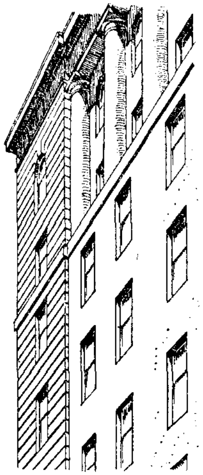

FIG. 66.

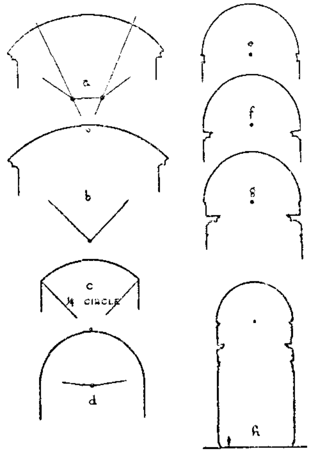

FIG. 67.

FIG. 66. The illusion referred to in Fig. 65 made worse firstly by rusticating the end bay, and secondly by use of an order with tapered and entasized columns just where it will do most harm.

FIG. 67.

a. Usual correction for segmental pediment. *b*. Segmental pediment uncorrected. *c*. The quarter-circle arch demands no correction. *d*. The live spring of the slightly depressed arch. *e, f, g, h*. Stilting related to projection of imposts and height above the eye.

In this connexion it is a great mistake to rusticate the quoins in the case of tall buildings or, as is often done, the end or angle bays. Repeated string-courses at sill levels, and so on, are also to be avoided. Pediments over window-heads have a value in distracting the attention from the horizontal lines of the actual window-heads. Interruptions to the long vertical line of the quoin by means of belt-courses and entablatures may also be resorted to, or the successive setting back of the wall face may be effective. Italian buildings of three or four stories in height treated with superimposed orders hardly suffer at all from the distortions we are here

considering. In such cases the profile is broken and the lines of heads and sills are boldly interrupted. In consequence the need of corrections does not arise. A strong cornice also goes a long way to set and keep the wall-head in its real place. Colonnades, especially of pilasters, hoisted up ten, or twenty, stories in the air, when seen in sharp perspective from the other side of a narrow street, suffer extremely from these effects of outhang and winding.

Foreshortening in cases where arches or vaults occur over strong imposts or cornices, especially in interiors, demands some form of stilting, if the arch or vault is to be apprehended as a full half-circle. In extreme cases, this stilting may be brought about by the use of a member between the impost or cornice and the actual spring of the arch or vault. Plinths, podia, or even attic stories may constitute such stilting members, as for example in St. Paul's Cathedral.

8. *Some Miscellaneous Refinements*

In conclusion a few miscellaneous refinements, which though not very general can be recommended.

Segmental cornices and lunettes and the straight lines joining their ends are mutually provocative of illusions. The ends of the curve tend to straighten out; a reduction of radius to give increased curvature is the remedy. The chord, on the other hand, appears to curve up towards its ends owing to the tendency towards the exaggeration of acute angles. The increase of curvature usually disposes of this difficulty as well, and correction of the chord is rare, if indeed it has ever been resorted to.

In window tracery, the old practice of reducing the width of the section used in the mullion as soon as curvature is introduced above the spring of the arch can hardly be too strongly insisted upon. In the near view from below, which is naturally the usual one for scrutiny, the soffits of the curving members come into view, and from void to void the curved members subtend a larger visual angle than is the case with the mullions. Consequently the curved members are apt to look thicker. From the far view they are apt to look a little thicker than they are, because they are in short lengths, while the mullions look thinner than they are, being in long lengths—a matter of proportional contrast. Apart from this, the tracery members of minor lights in the head usually drop one, or more, of the 'orders' which appear in the mullions, and this by contrast provokes a thickening in such tracery members as remain fully 'ordered' with the mullions. The spirit of the thing is somewhat parallel to that in the growth of trees: if branches are smaller than limbs, limbs may be expected to be smaller than trunks.

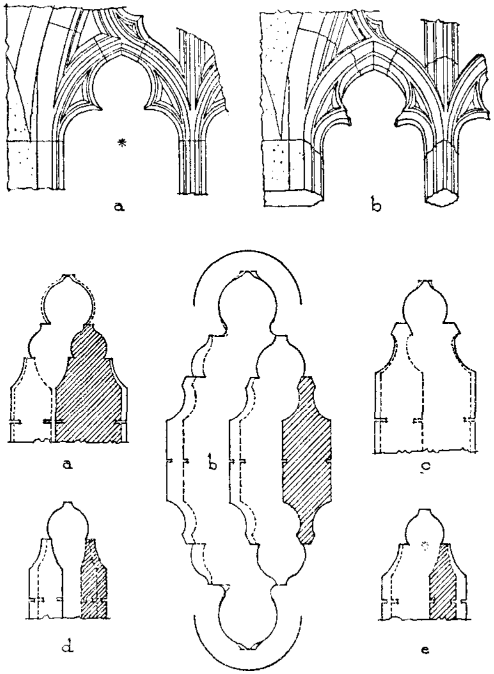

FIG. 68.

Above, tracery of a light-head in elevation and foreshortened.
Below, English fourteenth-century refinement of reduction of the mullion on entering the tracery.

There is also the case of the arched opening with the large hollowed outer section, so common in the architecture of the time of Louis XV in France. Here, in the ordinary front view from below, the hollow at the head, if the same as at the jamb, subtends a wider angle at the eye; but in an oblique view the jamb hollow shows at least as wide as that at the top. The usual correction is to make the hollow as deep vertically at the top as the chord of the hollow at the jamb, the hollow thus widening gradually from spring to top. So contrived, in all ordinary views the hollow preserves the charac-

ter of being not less wide at the top than at the jamb; it also mounts congruously with the lengthening voussoirs.

Another problem, which it is useful to know how to handle, is that which arises when circular drums or semicircular elements are associated with rectangular elements in a composition by the device of a common entablature. Suppose a great drum with a rectangle breaking out of it, from which in turn a half drum pro-

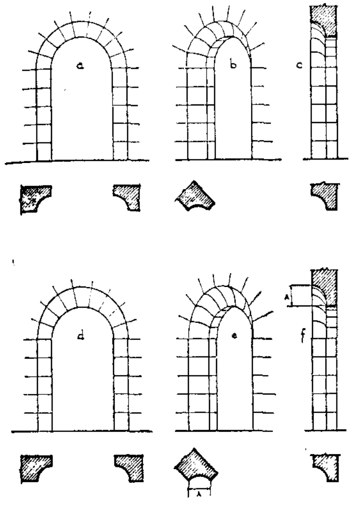

FIG. 69.

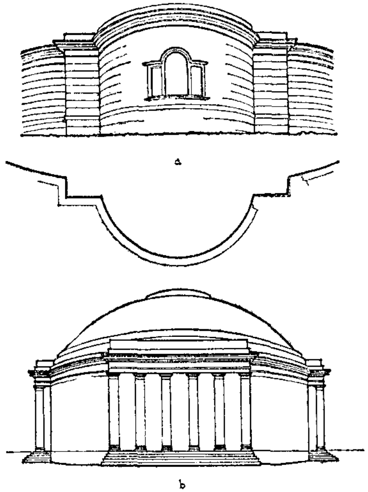

FIG. 70.

FIG. 69. The eighteenth-century French refinement of enlargement of the hollow jamb mould in the head of the arch.

FIG. 70.
a. Correction for straight wall associated with curved wall.
b. Unfortunate association of rectangular, cylindrical, and spherical elements.

trudes, the disconnected bits of the face of the rectangular element will then appear to be set at a considerable angle to one another, though actually in the same plane, and the parts of the cornice over these will appear to cock up in the air in exaggerated contrast with the curvature of the parts of the cornice on the large circular and small semicircular elements. The necessary correction was made in a somewhat similar case which arose in connexion with the lecture theatres at the University of Alberta, as for any ordinary view from the pavement opposite, by modifying the rectangular element so that it should look flat on the face. The quoins in this case were set back 7 in. from the true face.

9. *Columns and Pilasters*

When columns with an entasis are engaged with a wall, it is usual to engage them to a depth of only one-quarter diameter at the base. Then, in any view up to 45° from the front view, the right and left profiles remain the same and the column looks plumb, as well as being so. If engaged to a depth of half a diameter, then, in

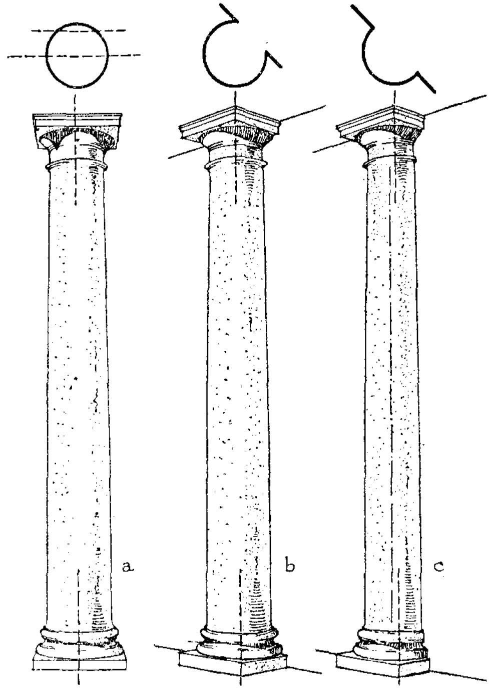

FIG. 71. Engaged columns.

like views, the outer entasis is more pronounced than the inner one and the column also shows as more slender than in the front view, and, worst of all, its axis, read as between its profiles, leans in towards the wall.

In handling classic orders involving free-standing columns with entasis and pilasters without batter and entasis, a difficulty often arises as to the relation of the face of the pilaster to the face of the frieze. The face of the frieze is usually in a plane with the face of the round shafts just above their bases: a pilaster two modules wide with a cap of less projection than that of the circular columns,

measured from the face, is not unusual. But such a pilaster, except when viewed in dead elevation, is apt to look a good deal wider than, and therefore in different proportion from, the columns. Pilaster shafts may well be made somewhat narrower than the base of the circular shafts. The frieze will then oversail the face of the pilaster slightly.

If it is decided to give batter and entasis to the pilasters the

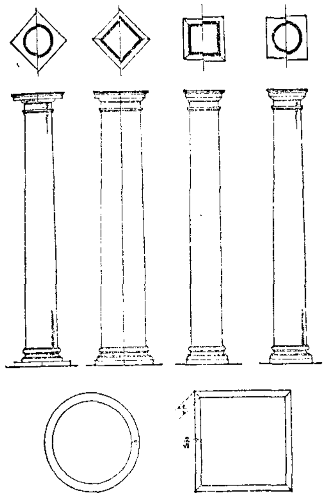

FIG. 72.

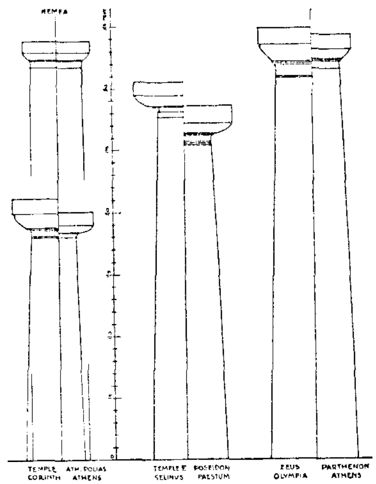

FIG. 73.

FIG. 72. Entasis for square pilasters regulated on the diagonal.

FIG. 73. Range of scale and form in Greek Doric columns.

question may arise, how much? If the same amount is given on the face of the pilaster as on the circular column, then, in the diagonal view, it will result in much more—1 as against $\sqrt{2}$—and some incongruous effects may be expected. Perhaps the best way is to give the pilaster an entasis which on the diagonal view will be the same as that for the columns, and in other views less.

All this sounds like Vitruvian lore and might well occur under the head of proportion. The main object in dealing with the matter in this place is to show that a refinement which is applicable to a circular column may require modification in the case of a square pilaster.

And last of all comes the question of entasis in columns. The entasized Doric shaft is historically a parent of all subsequent entasized shafts. History and evolution may appear to be against the suggestion that, in the Periclean period at least, the apportionment of entasis was an attempt at expression of structural consistency of stress, regardless of stressability. But bear in mind that, roughly speaking, what the archaic Doric column supported rarely exceeded its own mass. In the case of the Parthenon, as in

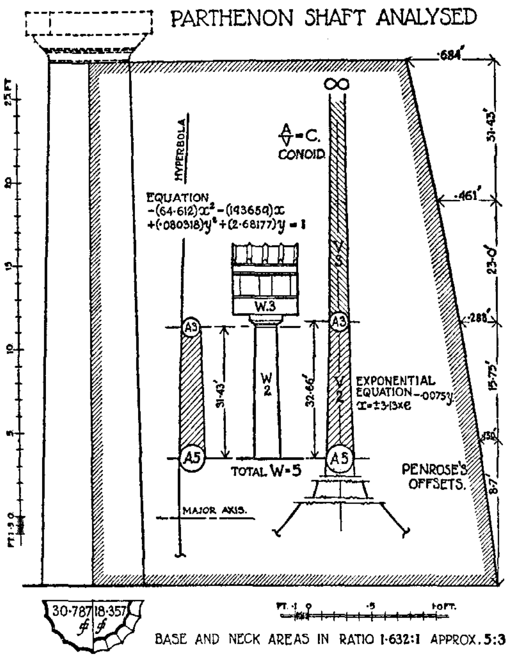

FIG. 74. Taper and entasis of the Parthenon shaft.

any pedimented temple, the columns of the peristyle are not all equally loaded. Those at the centres of the pediments carry most load and those on the flanks least. As these latter are numerous the average loading is only slightly in excess of what these latter bear; but if we take the mean neck load—half-way between the greatest and the least load borne on any of these columns at the neck—and the weight of the shaft we get this result. The mean load bears to the weight of the shaft the ratio 3 to 2. Now if we work out the area at the true neck and the area at the base we find these are in the ratio 3 to 5. The neck and the base are thus equally stressed in the case of the mean-loaded shafts. This consistency, of which any one can satisfy themselves by doing some mensuration and

arithmetic, taking into account the weight of the marble used, suggests that the designer of these columns may have arrived at their general form in a thoroughly engineering spirit though disregarding what there was no means of ascertaining—crushability.

Now what of the entasis—the curvature superimposed upon the batter arrived at as aforesaid? One may say it was a correction; but it is more than that, for it is obvious. One may call it a refinement and leave the matter there, saying that it 'satisfies the eye'. Does it? And if so why?

Assuming that Ictinus or Calicrates, or the pair of them, sought uniformity of stress as between the areas at the actual neck and at the base, one might expect him, or them, to be seeking uniformity of stress throughout the whole shaft. If so there was some fairly recondite geometry and mathematics then available for such a purpose. There is no doubt that the Greeks of Pericles' time knew nearly as much about the geometry of conic sections as we do to-day, but the exponential equation which enables one to set out a column with a constant ratio of area to volume was still twelve hundred years in the future. Such a column is concave in section and not convex.

Now it is curious to find that a column of this form (which represents what actually goes on in the shaft under consideration) would have its greatest variation from the straight profile of a true cone at about two-fifths above its base, just as in the case of the executed shaft in question; and that its amount would be about the same—seven-tenths of an inch; but this would be inwards, not outwards, from the true conical surface.

At this point it will be well to remark that while, generally speaking, early Doric columns have a very full entasis as compared with later ones, true conical shafts (i.e. without entasis) do occur in early examples; and Ictinus himself, after building the Parthenon with entasis on the columns, built the temple at Bassae with plain conical shafts. But no concave entasis appears ever to have been attempted. The difficulty of executing such a shaft by the Greek method of cutting down to the flutes after the column was set and making a presentable job of it would have been insuperable. There is much to be said on practical grounds for the contention that for a fluted shaft a full entasis is easier to execute than a delicate one, and a delicate entasis easier to carry out with apparent accuracy than a true conical form.

It may be observed here that it is generally accepted that when the Greek used entasis on columns the curvature increases towards the base. In subsequent classic tradition it is usually the other way—a corruption?

Now, reverting to the question of what the designers of the Parthenon were attempting to do, it seems quite possible that, with the mathematics at their disposal, they may have been aiming at equal stress throughout the shaft. If one superimposes a series of cylindrical blocks *of equal weight*, but each with a diameter greater than that above it, such that the differences of area are the same, one readily discovers that as the rings representing these successive differences grow larger they also grow thinner, for their areas are the same. If the cylinders were all of equal height a pronounced convex entasis would be the result. But in the case we are supposing they must diminish in height successively as one goes down, for they are assumed of equal cubic content. The question arises, do they diminish in height fast enough to neutralize convexity of contour. Further, there is the weight of each successive wedge section ring to take account of. As Newton had not been born the means of making this calculation was not available. Ictinus got his greatest variation from the straight line between neck and base at about the right place and he got about the right amount of variation; but he conceivably failed to realize that, delicate as the true curve is for constant stress, it is concave, not convex, to the shaft.

And now we come to Penrose's investigations. He was primarily a mathematician and had interested himself in geometric methods for predicting lunar eclipses. His measurements at the Parthenon were carried out with amazing delicacy and care and he arrives at the conclusion that the designers of the columns found a segment of the arm of a hyperbola to pass the neck, the base, and the point, two-fifths up from the base, where the deviation of the curve from the line joining base to neck was seven-tenths of an inch. This hyperbola has its major axis horizontal and below the base at a distance of a little more than two-fifths of the height of the shaft.

It is to be borne in mind that we are dealing with a curvature of less than seven-tenths of an inch in 31·43 feet. The requirements could be fulfilled by using a suitable segment of either of the other conic sections—parabola or ellipse. The parabola is ruled out for lack of a mechanical method convenient for setting it out. The ellipse can very easily be described with string or trammel, but an

ellipse with its major axis horizontal below the base does not flatten out quickly enough to satisfy the condition of passing the neck and would be as big as a town; while an ellipse with its major axis vertical would give quicker curvature at the top instead of at the bottom. The hyperbola can be described by continued motion;

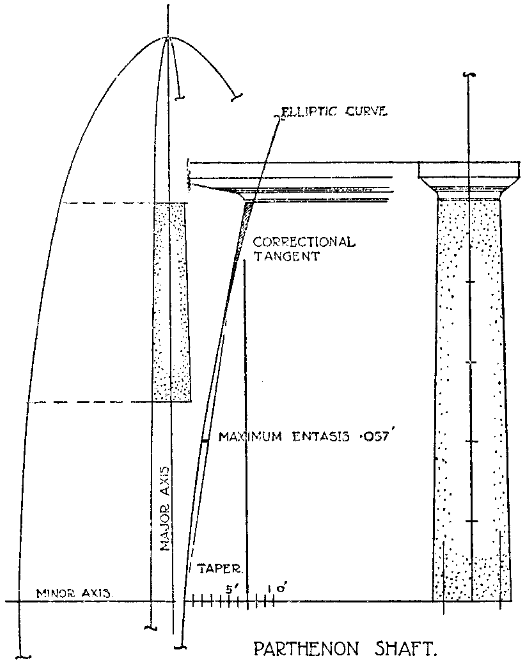

FIG. 75. Setting out for entasis by means of a conoid with tangential correction.

but it is an intricate operation. Of course, for practical reasons the curve could not be set out full size. What would be required practically would be a curve condensible above its axis to a scale large enough to allow the offsets to be measured.

It may be noted, and this is important, that Penrose gives his readings for offsets for one column, not the mean readings for a number. It appears by his admission that no two in the Parthenon are exactly alike; and the one he measured, though as good a one as he could find, was considerably bruised at the base and several of its drums were shifted; of course, not all of these were shifted in the same vertical plane. Conscientious as these measurements were, their result may fairly be taken with a pinch of salt; besides, there is 'builders' error' in the Parthenon—very little of it—but certainly enough to awaken consideration as to what is and what is not evidence in such a case of minute differences measured.

There is an alternative geometrical construction which will satisfy the conditions quite as accurately as the 'builders' error' would admit. It has the merits of simplicity and ease. It also has a certain inherent probability, as it assumes the shaft to be conceived as a regular conoid throughout a part of its length with the axis of the column coincident with the major axis of the curve used, and the rest, the upper part, corrected (into a cone) against the optical effect of the reverse curvature between the annulets and the neck.

If one generates an ellipse with its main axis on the axis of the column, such that it will pass the base, the point of widest curvature two-fifths up and the actual nick of the neck (not the face at the neck) it will be found to be about 178·0 ft. long, 6·8 ft. wide, with its foci about 3 in. from its ends. Only a part of this ellipse is needed and it might well be condensed to one-twentieth in length or even to a circle. The curve could then be scratched on a marble slab 8 ft. square. Base, neck, and the several drum joints could next be ruled off and the correction for the upper part be laid off as a tangent to the curve. The measurements for the work could then be taken.

We know, of course, that before setting the drums and cap the flutes were worked for an inch or so at the base and brought down from the annulets as far as the neck, which was a necessary 'work-form' to prevent the points spalling off in setting. The rest of the shaft was surplus to the finished radius and unfluted when set. It is interesting to conjecture just how the shaft was next reduced to conoid form, the arises of the flutes struck, and the flutes relieved. Something in the way of an adjustable template, gyrating as if secured to the axis of the column, would appear to have been necessary.

If we ever discover the actual method used in executing these flutes after erection of the shafts, which were certainly carried out with a precision beyond anything achieved in the Neo-Greek revival of the early nineteenth century, we shall be in a position to determine the nature of the geometrical setting-out in the stone-yard—the full-size detailing.

Meantime a practical stereotomist's guess is possibly as good as an astronomer's and is offered for what it is worth.

It seems possible, perhaps probable, that Ictinus was seeking to design a shaft of equal stress throughout and that he very nearly did so. That the stress he was dealing with was a very small one and that the material he was handling was capable of bearing a hundred times that stress with impunity need not disconcert us. He had no means of knowing what his material would stand; he was primarily concerned with stability in earthquakes; he was not conceiving Turks and the use of his masterpiece as a powder-magazine. But for that accident it is improbable that there would be a spalled joint in his shafts to-day. The ideal of a uniformly stressed shaft could hardly have escaped the attention of the Greek builders. How they worked out their curves is after all a secondary matter. Why the curves occur is the question of real importance. Ease of execution, without visible error or risk, is a quite probable answer.

The curve may be a selected segment from the arm of an arbitrarily placed hyperbola. It may even be in intention the precise hyperbola Penrose finds. But before accepting this curve at all we would have to know that it fitted a majority of the columns of the Parthenon (and that we never can know owing to their condition); and we should have to know how the setting out in the yard and on the job was accomplished. The alternative curve offered has merits in this latter connexion.