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ENTASIS AND OTHER REFINEMENTS IN GREEK TEMPLES

by

Joseph Arthur David Lorente, B.A.

A thesis submitted to the School
of Graduate Studies in partial
fulfilment of the requirements
for the degree of Master of Arts.

The University of Ottawa

Ottawa, Ontario

1979



Joseph A. David Lorente, Ottawa, Canada, 1979.

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ENTASIS AND OTHER REFINEMENTS IN THE GREEK TEMPLE

Entasis is the swelling in the central portions of the shaft of a column. Its nature, purpose, study and story are the main concerns of this thesis. It is one of the earliest of the Greek refinements and the only one that received much favor after the Greeks turned from the Doric to the Ionic and Corinthian styles. Such other refinements as are summarily discussed are those that seem to grow out of entasis or are closely related to it. In any case, the observations about entasis seem to apply broadly to the other refinements concerned.

In the extant writings of antiquity the word ἡ ἐντάσις was used only once in its architectural sense: Vitruvius used it in De Architectura - the only ancient manual on architecture and one that is sometimes deemed to be quite misleading on Greek styles. To further complicate matters, Vitruvius refers to an illustration which explains the technique, but that illustration has long been lost to us.

There is evidence that the principle of entasis was applied in Mesopotamia and in Egypt centuries before it apparently was 'created' in the Greek world. Yet the practice of applying a bulge to a shaft is generally said to have originated with the Greeks.

The Romans used entasis with 'gusto'; an expert on the subject knows of no Roman column without it. Nor did the practice die out during the Middle Ages. As one might expect, there was a revival of interest and application of entasis in Renaissance Italy when Vitruvius' book was reprinted and studied. The practice spread to European countries and eventually to the New World so that it is still found in 'neo-classical' and more particularly, in rustic North America - even in Ottawa and the Ottawa Valley. The supreme irony is that entasis was just 'discovered' in the Acropolis structures in the last century, and its existence in some structures was missed, by some who made the most careful and accurate calculations, and even disputed by others.

This work, then, examines the nature of entasis and suggests that, while the Greeks may indeed have invented it independently, there is strong probability that Egyptian and Mesopotamian influences were at play. The times and nature of contacts between Greeks and the Near East are touched on briefly. An attempt is made to offer a synthetic overview of such evidence as does exist about the nature of entasis. In this respect it should be observed that actual measurements exist in available publications for fewer than a dozen columns and one must suspect the conclusions that

are offered or the way in which the findings have been expressed.

The etymological significance is touched on, as is the nature of the entasis curve, its requirements and the conics and geometric and mathematical proofs involved. Tests are given for the hyperbola, parabola, ellipse, conchoid of Nichomedes and vertical projection of a helix. Some of Penrose's diagrams are reproduced and compared with those by Stephens. There is consideration of illusory and aesthetic factors and the possible implications of a canon based on human proportions. The list of extant temples is so catalogued that the reader can add more information about entasis as it becomes available and relate it to other pertinent data.

The author admits that there seems to be no conclusive proof for his feelings that entasis was arrived at by no hard and fast rule by the Greeks, no matter how precisely the curve was executed in individual cases. He awaits validation or rebuttal of his argument from someone armed with precise measurements and stereogrammetric information processed through a modern computer.

David Lorente,
1979.

PREFACE

Three and a half decades ago I was introduced to the Greek temple by the late Brother John Pollock, O.M.I., at Saint Patrick's College, Ottawa. For the last twenty - six years I have attempted to answer questions by Renfrew Collegiate students in my classes in art, ancient history and archaeology - questions relating to how and why the ancient Greeks should have used entasis and refinements in their temples. Fate decreed that I should do a seminar on the topic for Dr. Trevor Hodge at Carleton University at a time when I was searching for a Master's thesis topic. Certain aspects of the matter also interested Dr. Graham Webster of Birmingham University and he permitted me to conduct a seminar at his archaeological site to show how refinements might have been used in executing the famous Wroxeter Roman City inscription. The time seems ripe for me to commit myself to paper.

I am not unaware that I lack in-depth expertise in many of the areas that have a bearing on the topic and that this study may seem to range far and wide at times. The questions I have been asked over the years and the questions I have asked myself have largely determined my approach and dictated format. Accordingly, I have attempted to give a

broad survey of what experts have deemed to be the nature and purpose of entasis. Such refinements as are mentioned are treated summarily and only because they grow out of - or serve to clarify - the discussion of, entasis.

At the same time I should regard it as apt if this study in some small way becomes a testimonial to Brother Pollock's inspired teaching and to my students' curiosity. I should also like to express my gratitude to Dr. Hodge for his encouragement and assistance and to Dr. Edmund Bloedow for his guidance and patience.

This study is dedicated to my family, to my wife Kay, and to Des, Doug, Don, Jane, Dan and Dave. They have been my inspiration and staying power. They have suffered the consequences of a father's dedication to study.

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LIST OF ABBREVIATIONS

<u>AAG</u>	Dinsmoor, W.B., <u>The Architecture of Ancient Greece</u>
<u>AJA</u>	<u>American Journal of Archaeology</u>
<u>AM</u>	<u>Athenische Mitteilungen</u>
<u>BCH</u>	<u>Bulletin de Correspondance Hellénique</u>
<u>BSA</u>	<u>Annual of the British School at Athens</u>
<u>ERC</u>	Stevens, G.P., <u>Entasis of Roman Columns</u>
<u>GAW</u>	Coulton, J.J., <u>Greek Architects at Work</u>
<u>GRA</u>	Robertson, D.S., <u>Greek and Roman Architecture</u>
<u>GTTS</u>	Berve, Gruben, Hirmer, <u>Greek Temples, Theatres, and Shrines</u>
<u>JRIBA</u>	<u>Journal of the Royal Institute of British Architects</u>
<u>K&P</u>	Koldewey and Puchstein, <u>Die griechischen Tempel in Unteritalien und Sicilien</u>
<u>OCD</u>	<u>Oxford Classical Dictionary</u>
<u>RE</u>	<u>Realencyclopädie der classischen Altertumswissenschaft von Pauly-Wissowa</u>
<u>SWLA</u>	Marinatos, Sp., <u>Some Words about the Legend of Atlantis</u>

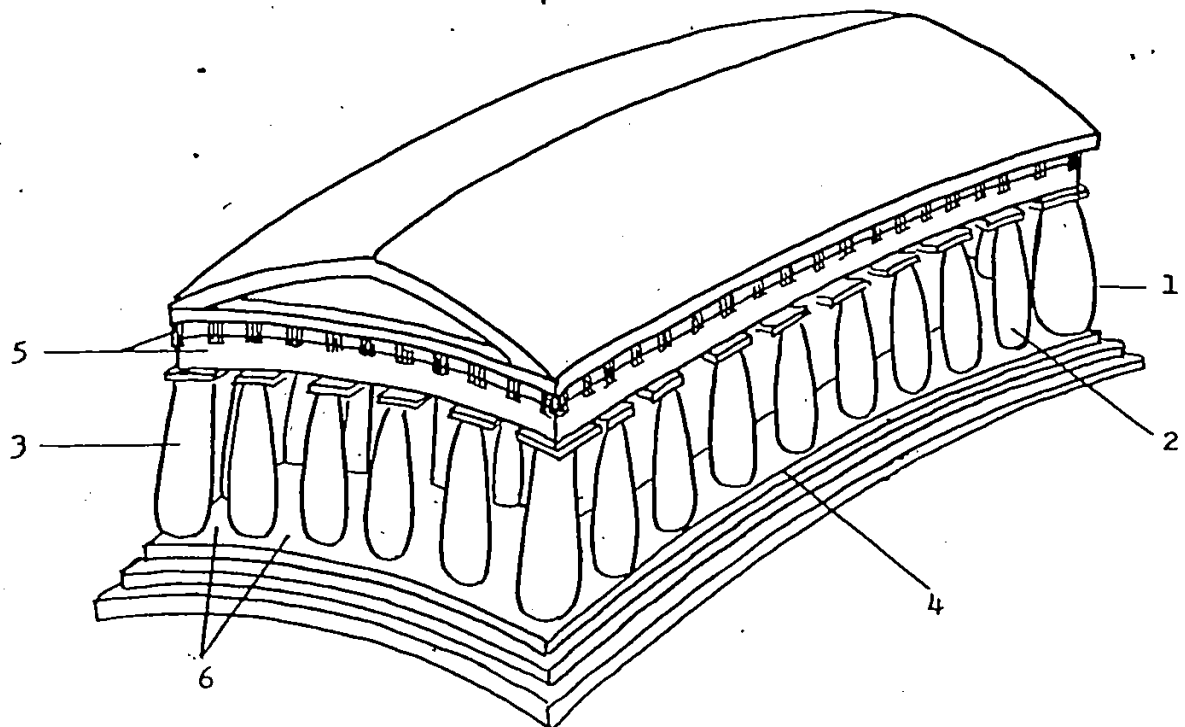
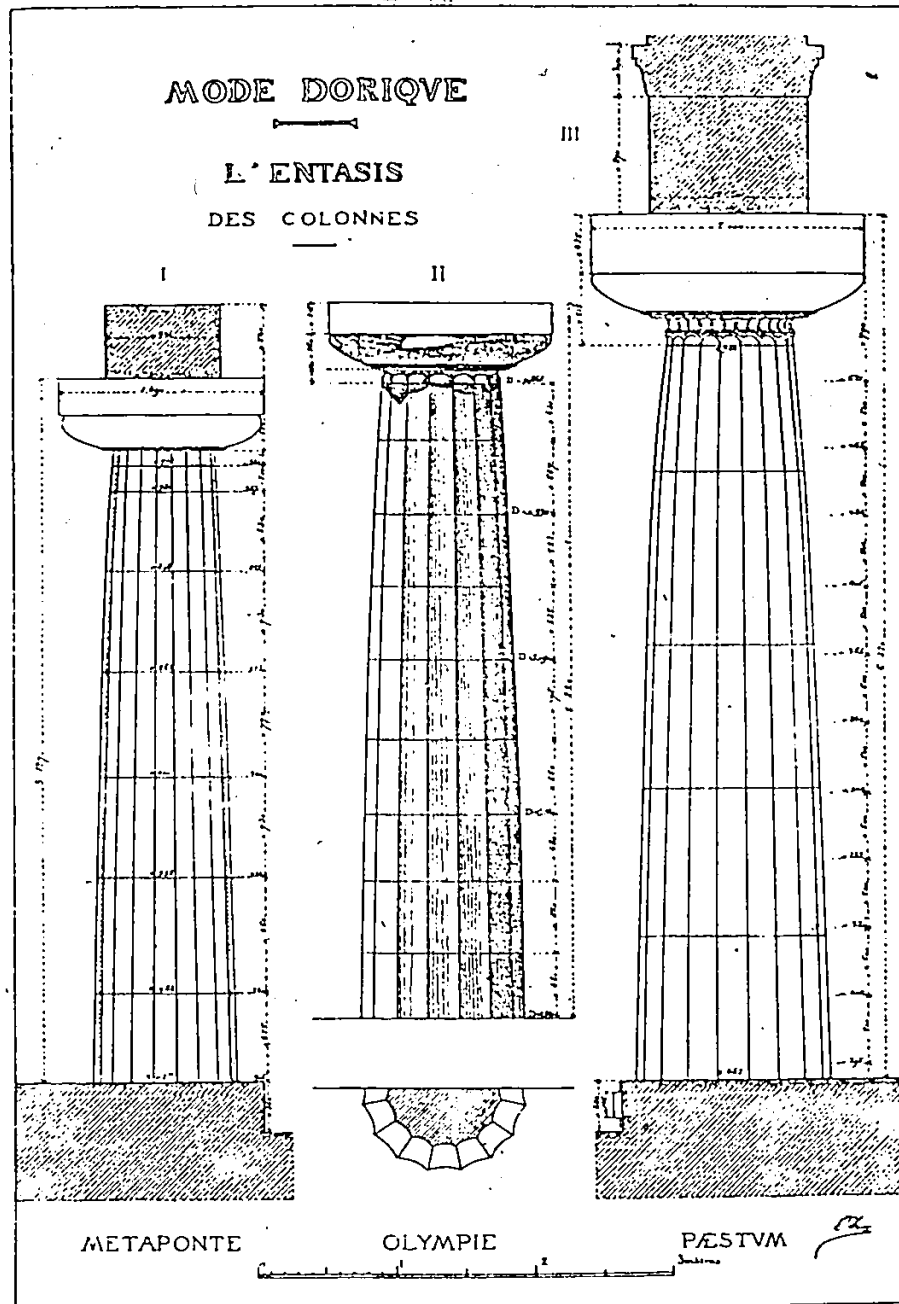


Fig. 1. Entasis and some refinements in the Doric temple (much exaggerated) (adapted from Coulton J.J., Greek Architects at Work, p. 108).

- | | |
|--|------------------------------------|
| 1. entasis | 4. curved stylobate and stereobate |
| 2. inclination of columns | 5. curved architrave and frieze |
| 3. two-way inclination of corner columns | 6. varied intercolumniation |
| 7. varied column diameter (1&2) | |



LA COLONNE DORIQUE

ÉLEVATIONS GÉOMÉTRALES

Fig. 2.

(Reproduced from: Choisy, Histoire de l'Architecture,
p.430.)

I

INTRODUCTION

1. Status Quaestionis

Virtually every student of the Greeks knows that straight lines in buildings like the Parthenon were the exception rather than the rule, that the Greeks, in short, used refinements. He may even know that the curve imparted to the vertical taper of a column is called entasis, and that the curve itself had all the characteristics of a sophisticated conic.

Should he pursue the matter a little further, however, he would do but little to clarify the nature of entasis and refinements, or indeed their purpose. He would instead open a Pandora's box of irresistibly fascinating questions. This study is my own attempt to confront some of these challenges, to reconcile conflicting information and to gather into a single treatise major conclusions which have been reached.

In the extant literature from antiquity the word entasis, in an architectural sense, appears only once - in Vitruvius, four centuries after the apogee of the application of the principle by Ictinus in the Parthenon. And while entasis was used in Roman times and sporadically

during the Middle Ages, it was not discussed in treatises on architecture until the Renaissance, when architecture in Italy tended to become a theoretical science and Vitruvius' De Architectura was republished. Ironically, the entasis in the Acropolis structures was re-discovered only in the nineteenth century. There was a brief revival of 'classical entasis' before the end of the century, but thereafter modern modular building techniques mitigated against its further use. Yet it was used even in the Ottawa Valley a few decades ago and is still to be seen in the columns on porches.

The student who seeks a definition will find, quite often, that entasis is said to be a Greek invention. He is offered no word or name or purpose for the earlier familiar curved profiles of Egyptian and Mesopotamian columns. Should he seek further details about the nature of the curve, he would find it parabolic, elliptical, or perhaps, hyperbolic; he would find this strange indeed, for the conic sections had not yet been invented when the Parthenon was built. Should he attempt to reconstruct a column with entasis, he would probably use a 'modernized' version of the Renaissance masters' techniques (Serlio's vertical projection of a screw line or Vignola's construction of a conchoid), and on turning to Vitruvius for an original technique, he would find that a) the description is cryptic, b) the illustration and the technique to which Vitruvius referred are, in fact, not to be found in his

treatise, and c) there is some doubt whether Vitruvius did indeed have the old Greek recipe. One could turn to photographs, of course, but cameras have been known to lie. The temples themselves are all too often in a state of disrepair, and accurate measurements - even if cost permitted - are, in many cases, not possible. Koldewey and Puchstein lament the fact that exact studies have not been made of all their sites and they blame the cost of erecting scaffolding.¹

Indeed, the nature of such 'modern' scholarly research as is available is limiting. No current volume is devoted to the subject. The word entasis is only sometimes listed in an index or glossary and detailed references are few; the word refinement is hardly ever noted. Dombart, in his article on entasis in the Realencyclopädie (1924) cites only eight ancient and modern literary references: Vitruvius of the Augustan period is the only ancient source. Serlio and Vignola of Renaissance Italy come a millenium and a half later. In the nineteenth century there are the Englishmen Penrose and Pennethorne as well as the Germans Thiersch and Hauck. Finally, there is Goodyear, the American who published only 800 copies of his monograph on the subjective nature of refinements in 1912.² There

¹Koldewey, R. und Puchstein, O., Die griechischen Tempel in Unteritalien und Sicilien, Asher, Berlin, 1899, as in, Goodyear, W.H., Greek Refinements, Yale University Press, Yale, 1912, pp.131,136.

²Dombart, T., RE Suppl IV, 1924, s.v. Entasis, cols. 270-276.

is no convenient collection of inscriptions relating to Greek architecture.¹ Vitruvius, though he comes four centuries after the Greeks used entasis and refinements in their most subtle forms in the Doric Parthenon, is our most important author - and he belongs to the Ionic tradition. Any other writer refers to architecture only in passing. .

Defining and determining the nature of refinements is almost equally frustrating or challenging. Time, place and the author's expertise are factors. One can find reference to the more obvious 'niceties' such as inclination of columns, stylobate curvature and varied intercolumniation in most studies. Such features as are sometimes termed 'refinements' are catalogued on pages 10 - 12 of this study. One wonders about accepting polychromy, ichnographic proportions, moulding curves, fine carving in the arris, and the like as legitimate refinements. There is an obvious need to exclude and restrict.

There is a final limiting factor, not so much on the evidence as such, but on how the evidence is used. That factor is the person using it. That is a truism, perhaps, about any researcher, but in this particular case another factor is at play. Most of the treatises which include discussions of entasis and refinements have been

¹Coulton, J.J., Greek Architects at Work, Paul Elek, London, 1977, p.182.

written by experts in other fields. Ideally therefore, one ought to be a practising architect and engineer as well as an expert in optics, numerology, metrology, archaeology, archaeo-astronomy, higher mathematics, the history of mathematics, photography, Gestalt psychology, and even art and aesthetics, in order to be able to assess fully a given discussion. I make no such pretence, but have striven to evaluate the relevant discussions to the best of my ability.

2. Object and Scope

The main object of this study is to provide a synthetic overview of the available evidence and to examine it critically so that it can be shown what stage the problem has reached in present-day scholarship. The paucity of material and written evidence will limit the scope very considerably inasmuch as our concern is with the Doric temple from the time entasis first appears during the colonization of Magna Graecia until the age of Pericles when it is the only 'nicety' to survive the new preference for the Ionic and Corinthian styles.¹ One must perforce examine the precedents and the more numerous later Roman, Renaissance, and even 'modern' and-contemporary examples in order to see better the 'Doric episode in Greece' in perspective.

¹Coulton, GAW, p.111.

Illustrations and considerations of selected non-Greek examples have been incorporated in this study only if it was thought that they might shed some light on our understanding of entasis as the Greeks might have used it. Refinements are dealt with in the same way. Only those few that serve as secondary illustrations of the entasis problem are considered.

3. The Evidence

Material remains of temples/structures

Mention has already been made of the sad state of most Doric temples. Wars, time, pillaging, defacing, earthquakes, earth movements, erosion, settling and use, abuse and disuse have taken their toll. Little remains that can be accurately measured and even then, cost has prevented those who tried from achieving any great success. Precisely because there is no compendium of up-to-date information relating to entasis and refinements, several appendices have been added to this study. One is an adaptation of Dinsmoor's chronological list of all Doric temples.¹ His recent, authoritative and complete statistics are retained (in spite of the fact that they make no direct mention of entasis and refinements) because the information, e.g., ratios, proportions and dimensions, sometimes has a bearing on our consideration of entasis. To this list is

¹Dinsmoor, William Bell, The Architecture of Ancient Greece, W.W. Norton & Co., New York, 1975, pp.340 a-f.

added data about the existence of vertical or horizontal curvature, so that one can, for instance, seem to trace the development of Greek entasis from extant temples in Metapontum and Paestum (or possibly Olympia) to the Acropolis.¹ One can also see which temples had entasis and which did not and whether there is an apparent correlation between entasis and horizontal curvature or even curve in plan.² The open-ended aspect of this appendix on the one hand reveals what little information is available, and on the other, offers a place to compile it in relation to other pertinent facts. Another appendix gives actual references to entasis by Dinsmoor, Robertson, Lawrence, Goodyear, Coulton, Cook et al.³ No one pretends that the list is exhaustive, but it does indicate that hard figures are given for only eight temples - and five of these were measured by Penrose.⁴ So much for paucity of evidence! This appendix also lists the temples by place and name and so indents each that its location in west,

¹We have information for but a small percentage of the total number of temples ever built, so our evidence could be misleading. Other factors must be considered, e.g., entasis seems to appear in the colonies first, but other refinements such as angle contraction apparently originated on the mainland and reached the colonies only one hundred years later around 480 B.C. (Dinsmoor, AAG, p.105.)

²The Temple of Apollo at Corinth (540 B.C.), for instance, has no entasis and a limited type of horizontal curve.

³Reference is made to page, figures, illustrations and measurements.

⁴Parthenon, Erechtheum, Propylaea, 'Theseum' and Temple of Zeus Olympius by Penrose; the Olympia Heraeum by Coulton; the Basilica and the Temple of Athena or Demeter at Paestum by Koldewey and Puchstein.

east, or mainland, is visibly apparent. Appendix IV features maps on which to locate the sites and geographic parameters of the study.

Ancient literary references

Except for Vitruvius, ancient writers refer to the broad field of architecture only in passing. To be sure, other architects, like Ictinus and Callicrates, are said to have written books explaining their works. These have all been lost to us; we know about the books, but that is all. And if references to architecture by ancient writers are incidental, the references to entasis and refinements are virtually non-existent. A perusal of the 'refinements' listed on pages 10 to 12 will reveal the almost utter hopelessness of trying to find them in the index to any ancient document. One must rely chiefly on a chance reference here or there. The maturation of archaeo-astronomy, or astroarchaeology, has brought many books on the market of late, and these often suggest written or physical evidence and new avenues of consideration. On the other hand, R.L. Scranton's guide to the inscriptions pertaining to architecture in Harvard Library Bulletin 14 (1960) pages 159-182 and the ancient sources cited by J.J. Coulton in his recent Greek Architects at Work (1977) are perhaps the most useful documents outlining available literary references.

4. Definition of Terms

We have already called entasis 'the curve imparted to the vertical taper of a column'. That will be our broad working definition - our genus, as it were, because we must refer to the Babylonian and Egyptian predecessors. Our differentia will refer to the nature of the curve (its mathematical characteristics, the amount of curvature and its position relative to such factors as the height of the column), to the purpose (aesthetic, illusory or optical), and to time and place. This is the concern of the next chapter.

'Refinements' are sometimes construed as 'niceties' or 'subtleties' of construction, and though the number of refinements in the Doric temple, especially in the Parthenon, can approach three score, we shall concern ourselves with those few that are closely interrelated with entasis and contribute most to the final impression of the structure. In this regard, the question of horizontal curvature will be treated much like entasis. Inclination of columns and variations from the normal dimensions are the other closely related refinements with which we are concerned. The following is a list of features sometimes termed 'refinements':

ABACI, asymmetric dimensions, inclination of planes
 ACHOTERIA, inclinations
 ACTION of the Doric temple
 ANTAE, inclinations
 ANTEFIXES, inclinations
 ARCHITRAVE, curved
 ASYMMETRIC DIMENSIONS or MEASUREMENTS
 BACK OF PEDIMENTAL SCULPTURE CARVED IN DETAIL, finished
 BUILDING OUT OF PARALLEL WITH OTHERS
 CAPITALS, asymmetric dimensions
 COLUMNS, relative dimensions, inclinations to facade or
 side, inclination to corners, variations in
 fluting, asymmetric dimensions, asymmetric
 spacing, contraction of intercolumniation,
 nature and degree of entasis, size of projected
 entasis curve, location of vertex of entasis curve
 CONTRACTION of intercolumniation at the angles
 CONCAVE CURVATURE in plan
 CONVEX CURVATURE in plan
 CORNER COLUMNS INCLINED
 CORNICE, inclinations of the vertical face
 CORONA, inclination
 COUNTERSUNK CORNERS of stylobate, stereobate
 CURVATURE, horizontal, supposed use to correct sagging
 effect, as an aesthetic consideration, convex in
 plan, concave in plan, curves in the raking gables,

curvature in the entablature, limited to the
 façade, limited to the flank, dimensions of the
 projected curve; vertical (see entasis)

CURVES in mouldings, fluting

DIMINUTION of Doric shaft and effect on perspective illusion

DIRECTION OF INCLINATION, degree of

ENTABLATURE, curved, inclined

ENTASIS, type of curve, location of maximum entasis, ratio
 of maximum entasis to other measurements, in columns,
 in door jambs, pilasters

FINE CARVING in arris, hard-to-see frieze, backs of pedimental
 sculpture, etc.

FRIEZE INCLINED, position of

GABLE, raking lines curved, bent upward, prescriptions

ICHTHOGRAPHIC PROPORTIONS

INCLINATIONS, measurements, prescriptions, in antae,
 architrave, columns, frieze, gable, entablature,
 pediment, steps, tympanum, walls

INSCRIPTIONS, dimensions corrected to achieve optical
 uniformity

INTERCOLUMNIATION, asymmetric measurements

MARGIN OF MASON'S ERROR

METOPES, asymmetric variations

OPTICAL CORRECTIONS, eg. in inscriptions, etc.

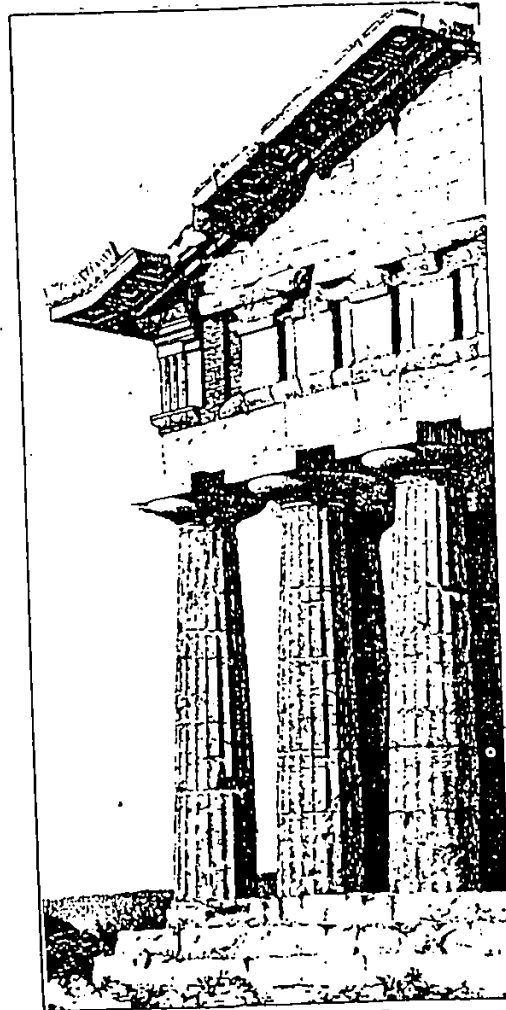
PERSPECTIVE, curvilinear, illusions

POLYCHROMY**POSITION** of frieze, end columns, etc.**PROPORTIONS** and **RATIO** of measurements**STEPS**, curvature or lack of curvature**STEREOBATE**, curvature, dimensions**STYLOBATE**, curvature, dimensions**TRIGLYPHS**, asymmetric dimensions, off-centered, related

to spatial contraction of columns

TYMPANUM, inclination.**VIBRATORY EFFECTS** of architectural asymmetries

This list of refinements is not exhaustive. It is, perhaps, extensive enough to indicate why any reference to refinements has been confined only to those that illustrate or amplify the discussion of entasis. It will also suggest that horizontal curvature deserves more consideration than the other anomalies because it is the only other large scale refinement in which the entasis principles seem to be used.



—TEMPLE OF DEMETER AT PAESTUM.
PARTLY RESTORED. (Koldewey.)



ENTASIS OF
DORIC
COLUMNS.

Fig. 3. a. Entasis in partly restored Temple at Paestum
b. Entasis in cross-sections

(Reproduced from Dinsmoor, W.B., The Architecture of Ancient Greece, pp.95, 169.)

II

ENTASIS

1. Etymological Significance and Definition

Etymologically, the term ἡ ἔντασις (entasis: inscribing, tension, straining) comes from the verbal form ἐντείνω (stretch [or] strain tight [especially of any operation performed with straps or cords]; stretch [a bow] tight, bend [it for shooting]).

We don't really know how entasis as an architectural refinement was arrived at, or how it was put on the column, or indeed what the Greeks thought its purpose was. We do know, however, that while our earliest encounter with the term in an architectural sense is in Vitruvius, it did have other meanings in other contexts and an examination of these might prove useful.

Liddell & Scott give the following entry for

ἡ ἔντασις 1. inscribing εἰς τὸν κύκλον [Plato, Menex. 87 b]; II. 1. tension, straining, τοῦ ὑποχονδρίου [Hippocrates, ἐπίδημία 3.1.]; τοῦ σώματος [Hippocrates, περὶ ἀέρων ὑδάτων πυρῶν 4] τῶν ῥάβδων [Hippocrates, περὶ ἀγμῶν 30]; ὀφθαλμῶν fixed stare [probably in Aretaeus Medicus, χρονίων νούσων θεραπευτικόν 1.3]; distension, αἰδοίων [Galenus Medicus, 7. 728];

2. exertion [Plutarch 2.948b; Aretaeus Medicus; *περὶ αἰτιῶν καὶ σημείων ὀξέωπαθῶν*, 2.2]; pl.
 retchings [Aretaeus Medicus, *χρονίων νοῦγων θεραπευτικόν*
 2.13] 3. ἡ τοῦ προτύπου ἐντάσις
 the assumption of a serious face [Lucian, *Symposium* 28];
 earnestness, *περὶ ἐκάστου* [Porphyry, *de*
Abstinentia 1.54]; strictness. *νόμων* [PSorb. 675.14
 (3rd Century A.D.)]; 4. architecture: swelling [in the
 outline of a column] [Vitruvius, *de Architectura* 3.3.13].¹

It may suffice to observe that virtually all these references can be related to the nature of, or application of, entasis in the column; inscribing might relate to the technique for arriving at the curve or making a model to serve as guide; tension and straining might refer to the wire that was perhaps used in a primitive form of 'pointing'; staring could refer to the art of plumbing a line visually or to the concentration required to detect the subtlest entasis; distention and exertion might indicate the nature and role of the extra swelling; the assumption of a serious face echoes earnestness and strictness as well as the care with which the process had to be carried out. The many

¹Liddell & Scott, s.v. ἐντάσις

references to physical exertion are entirely in harmony with the fact that the Doric is said to be the masculine order which derived its form from male proportions, and so the suggestion of tension appropriately echoes the function of the column in relation to the lintel or architrave. (It is also significant, perhaps, that in the Ionic or feminine order entasis was barely perceptible or even non-existent.)

Vitruvius called ἡ ἐντασις the adjectio quae adicitur in mediis columnis.¹ This swelling in the middle parts of the shaft presumably corrected a disagreeable optical illusion;² it was the compensation to counter the apparent concavity of a straight-tapering column,³ but it also served to impart life, vitality and an organic aspect to the architectural member.⁴

¹Vitruvius, De Architectura, III, 3, 13.

²Penrose, F.C., An Investigation of the Principles of Athenian Architecture, reprint of 2nd ed. of 1888, McGrath, Washington, 1973, p.103.

³Heron of Alexandria, Definitions, 135, 13
Damian /Hermodorus, Optics, p.28-30.

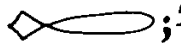
⁴Lawrence, A.W., Greek Architecture, Penguin, Harmondsworth, 1957, p.170.

2. Possible Origins

It can be argued that the principle of entasis did not originate in Greece. Curvature was certainly imparted to buildings in Mesopotamia and in Egypt centuries before it was used on the Acropolis.

Sumerian designers appear to have discovered the part played by optical illusion in architecture, a discovery, or rediscovery, of the builders of the Parthenon. In effect, there are no long straight lines at all in the Ur ziggurat, but the line of every wall and of every superstructure is imperceptibly curved or convected, so that the observer, by the principle of entasis, receives an impression of both strength and lightness.¹

Strabo also hinted at a curved aspect of the columns made in early Babylonia.² (See hypothetical reconstruction on page 18.) Dombart also refers to the Babylonian precedent and to 'an original Egyptian forerunner'.³

A swelling of the shaft of a column is characteristic of wooden and stone prototypes in Egypt, where Pennethorne thinks the practice began.⁴ It is interesting to note that in the New Kingdom the hieroglyph for column was ;⁵

¹Wellard, James, Babylon, Schocken Books, New York, 1974, p.91, (my emphasis).

²Strabo, Geography, 739.

³Dombart, T., RE Suppl. IV, 1924, col. 270.

⁴Pennethorne, J., The Geometry and Optics of Ancient Architecture, 1878, p.120.

⁵Badaway, Alexander, A History of Egyptian Architecture, (The Empire), University of California Press, Berkley and Los Angeles, 1968, p.527.

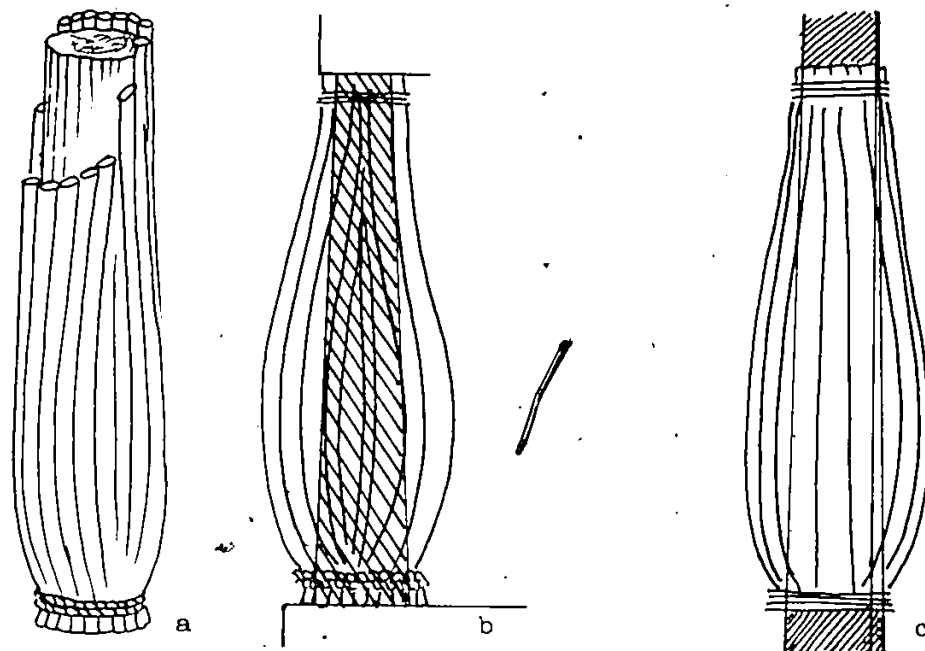


Fig. 4. Hypothetical Reconstruction of the Babylonian Techniques for Building Columns according to Strabo.

In method 1 (a and b) the tapered wood core is covered with reeds which themselves are tapered but which are cut longer than the core. These reeds bulge under pressure of the lintel.

In method 2 (c) the reeds are so laced at top and bottom that they sag under the weight of the stucco covering and form entasis.

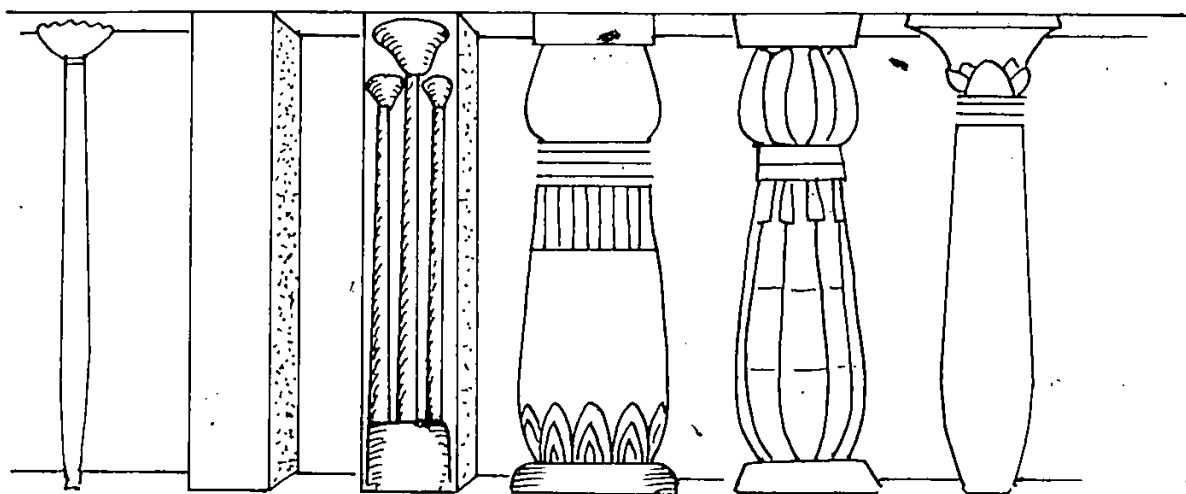


Fig. 5. Hypothetical Reconstruction of the transition from wooden post to stone shaft to decorated (relief) pillar, then to single round and bundle columns and finally to a lotiform capital with 'stalk' with entasis, as it might have occurred in Egypt.

in the Middle Kingdom the same symbol was vertical. Badaway spells out the literal meaning to help us better interpret the Egyptian concept: "wooden column with entasis in shaft, capital and top tenon".¹ Furthermore, an examination of the nature of tall wooden elements in Egyptian paintings will show that columns almost always have entasis, but equally long pieces of lumber in machines, ship masts, etc. do not feature the bulge.² It would seem that entasis was a curve that the Egyptians came to associate with the architectonic role of the column and which they later extended to such elements as the pylon, pilasters, obelisks and the like.

One must perforce mention the famous Egyptian 'Proto-Doric' columns of Beni-Hasan, Karnak and Der-el-Bahari in Thebes. Many believe - as the name implies - that these columns greatly influenced the Greeks precisely when they were translating the Doric column into stone. But Dinsmoor thinks not, on the grounds that early Greek Doric columns

¹Badaway, Alexander, A History of Egyptian Architecture, (The First Intermediate Period, The Middle Kingdom and the Second Intermediate Period), University of California Press, Berkley and Los Angeles, 1966, p.259, (my emphasis).

²Mekitarian, Arpag, Egyptian Painting, Skira, New York, 1956, pp.80, 106, 125.

were too squat, had too pronounced a taper and put different emphasis on such elements as abacus and echinus. He questions why the Greeks should have copied but one of many Egyptian columns, and that one a type that had ceased to be employed six hundred years before the earliest Greek stone columns. He feels that the influence for the Doric form came from early wooden columns not unlike the early Aegean types which the Dorians must have known through copies of the columns on the Lion Gate and Tomb of Agamemnon. Only reluctantly does he allow that the 'proto-Doric' does 'to be sure...bear a superficial resemblance' to the Greek Doric.¹

It is probable that both sides in the 'Proto-Doric' question are right. Dinsmoor admits that the earliest stone small scale columns of the temple of Athena Pronaea at Delphi are exceedingly slender and he does not argue against an Egyptian influence in Greek architecture per se. Indeed, he credits Egypt with a strong role in the development of the proto-Ionic capital which, he says, passed from Egypt to Mesopotamia, so that it is found in representations of actual columns on the sun-god tablet of Nabu-apaliddina (885-852 B.C.) from Sippara and on dado reliefs from the palace of Sargon II (722-705 B.C.) at Khorsabad.² He

¹Dinsmoor, W.B., AAG, pp.55-56.

²Dinsmoor, W.B., AAG, p. 61.

mentions influences in the sixth century throne room of the palace of Nebuchadnezzar at Babylon and then he says:

From such sources there were direct contacts with the Greek cities; for there were Ionians in the service of Sennacherib (705-681 B.C.), and the brother of the poet Alcaeus was similarly attached to Nebuchadnezzar (605-562 B.C.).¹

If we can show there was Greek contact with Egypt when the 'Proto-Doric' column was still in vogue and also when the Greeks started to build their columns in stone, then we shall have made a strong argument for an Egyptian influence. More important, we shall not have denied that there could also be equally strong influences from the media and from native Greek tradition. There is no reason why one influence should exclude the other completely. But most important, one should note that Dinsmoor never once refers to entasis in his arguments against an Egyptian influence on the Greek Doric column; he feels there is a strong influence from Mycenaean times; he cites significant dates and places and an alternate route that would also pass on the Mesopotamian influence which we have already discussed.

The Proto-Doric column appeared early on the banks of the Nile at Sakkara. The "curved planes and delicate fluting seem at times to anticipate the Doric refinements

¹Dinsmoor, W.B., AAG, p. 61.

of classical Greece".¹ That the style passed in Egypt is of no great significance. Might not Greek visitors have seen the column in use in its heyday? And if they saw some solitary sample centuries after it ceased to be a favorite form to the Egyptians, might not some Greek have been impressed in part because of the column's rarity? Greeks were Greeks, after all they did not have Egyptian tastes. It should be noted that the columnar forms that were retained in Egypt invariably had a strong bulge in the shaft in stone. There is every reason to believe too that in timeless, ultra-conservative Egypt the columns in ordinary mortals' houses were constructed in a manner not unlike the Babylonian. (See hypothetical development of the column on page 18.) Any Greek visitor to Egypt at any time after the pyramid age could have seen a column that suggested the entasis principle to him.² (And here we must make a distinction between Greek

¹Lloyd, Seton, The Art of the Ancient Near East, Praeger, New York, Washington, 1961, p.262.

²There is other strong evidence of the Greeks borrowing from Egypt: monumental sculpture, bronze casting and perhaps the idea of caryatids.

use of entasis and the curve used by Egyptians and sometimes by Romans. When Robertson, for instance, says that entasis was 'perhaps an Achaean invention'¹ we must assume that he is defining entasis in the strictest Greek sense: a very slight convexity of the column's taper which was seldom obvious and which never exceeded the base diameter of the column.)

Marinatos sketches the story of Creto- Mycenaean and Greek contact with Egypt from the second millenium on as proof for his theory that Mycenaeans - mainlanders, and not Cretans - helped drive the Hyksos out of Egypt. "These stout but simple warriors brought new burial customs from Egypt, the mummies, face masks, funeral stelae and the rich funeral furnishings."² And he adds that the mercenaries from the Aegean area never ceased to assist the Egyptians, that they were employed in Syria during the Amarna period, that there was constant intercourse between Egypt and the mainland from the 16th century onwards, especially during Egypt's last blaze of glory in the 26th dynasty (Saite) (663-525 B.C.).

¹Robertson, D.S., Greek and Roman Architecture, Cambridge, 1974 reprint, p.116.

²Marinatos, Sp., Some Words About the Legend of Atlantis, Chrys. Papachrysanthou S.A. Grafic Arts, Athens, 1972, p.28, (my emphasis). Might these new customs not have included a new respect and look at the column? Vermeule and others have written more authoritative works on the subject, perhaps, but Marinatos was a Greek, and so his words seem all the more interesting.

During this time Psammetich used Carian and mainly Ionian mercenaries to conquer Syria and fight the Scythians. His son, Necho, also relied on the Greeks and offered his victory gifts to Apollo of the Branchidae and not to Ammon of Thebes. His son Psammetich II (593-588 B.C.) in turn led Greek mercenaries, this time to Abu Simbel where they carved their inscriptions in the colossal statue of Rameses II. The Aegean visitors were even immortalized in Egyptian tomb paintings (reproduced by Marinatos) at Thebes (tomb of Rekhmara) and at Medinet Habu.¹ At both places there were - and are - extant examples of curvature in columns and in horizontal elements of buildings. It is hard to believe that the ever-inquisitive Greeks did not notice. It is hard to believe that there might not have been an Egyptian influence on Doric buildings or on Mycenaean columns.

That is why both sides in the Proto-Doric dispute might be right. Those who would have us believe that the Greeks were influenced only by native Aegean columns such as the Lion Gate and 'Tomb of Agamemnon' columns, might in fact be saying that the Egyptian influence was there - on those very columns - but many times removed from Egypt by the early classical era when there were other undeniable influences at work.

¹Marinatos, Sp., SWLA, pp.26-32, 36, 38-39.

And when entasis did start in the Greek world, did it start on the mainland or elsewhere? Some early columns at the Heraeum (ca 590) at Olympia presumably had entasis¹ but we have no evidence in extant ruins to support the certain existence of entasis until ca 535 when Selinus D was given columnar curvature.² We might also ask if mainlanders or colonials introduced the curvature at Olympia, for Olympia's role as a regular pan-Hellenic gathering place should not be overlooked.³

¹Coulton, GAW, p.176.

²Several other sixth century temples in the west came next: Paestum: 'Basilica' (ca 530) and Temple of Athena or Demeter (ca 510), Selinus: GT (520-450), Metapontum: Tavole Palatine (500) and Acragas: Herakles (500). See Appendix III.

³Consider too that there was much movement at that time. Phocaea, with other Greeks, had already pioneered the exploration and the colonization of the western Mediterranean. When the Persians attacked her in 540 (note the date) her inhabitants slipped out to Elea in Italy where they started the second school of Ionian speculation in the west (cf. Wormell, Donald Ernest Wilson, "Phocaea", OCD, 2nd ed., Clarendon, Oxford, 1973 p.826.) Pythagoras of Samos, by the way, had moved to Croton about the same time. In any case, the new settlers were certainly capable of discussing the pros and cons of entasis and of writing learned treatises on the topic. They certainly influenced architecture, but we cannot say by how much. (Cook, J.M., The Greeks in Ionia and the East, Thames and Hudson, London, 1963, p.111.) Greek ships had visited Egypt. Pausanias refers to these same Eleans honoring Ammonian Hera and Ammon's friend Hermes at Olympia where they had also erected an inscription honoring those men who, from a very early period, had visited Ammon at the Libyan oracle at the Oasis of Siwah. (Pausanias, V.16 1.)

The Ionian influence was certainly felt in the colonies as well as at Olympia.¹ Winter supposes that in the Temples of Hera and Athena at Paestum the strong entasis was designed to echo in Doric the slender proportions of the Ionic by stressing the relatively slender upper diameter of the shaft.² Dombart and Thiersch said essentially the same thing.³ Holdewey and Puchstein observe that "the oldest columns appear not to be swollen or only very little; then suddenly the columns of the Enneastyle and of the Tavole at Metapontum....show very strong swelling."⁴ This could suggest that entasis existed in a subtle form - perhaps on the mainland or in Ionia - before it got its strongest expression in the colonies, where builders were

¹Berve, H. and Gruben, G., Greek Temples, Theatres and Shrines, Abrams, New York, 1963, pp. 445, 447, 454. Gruben notes how the Ionian imagination sprang from the fruitful encounter with the wise civilizations of the East, with Egypt and Babylon, how Samos' very greatest flowering occurred in the 530's and how it surveyed (but not subserviently) what was familiar to it from the Orient through Cyprus and Egypt; he gives examples of borrowings in the proto-geometric period and concludes that the example of Egypt gave the Ionians the 'courage' to build on a colossal scale. Might they not also have received the courage to try entasis? See also: Coulton, GAW, pp. 333-334; Robertson, GRA, pp. 5, 60, 64, concedes an Egyptian influence in the Ionic and a 'stimulating effect' after the seventh century. He also holds that entasis was probably an Achaean invention (Paestum and Metapontum were Achaean colonies) and that it is doubtful if entasis occurred on the mainland before the fifth century (p. 116); Akurgal, Ekrem, The Art of Greece, Its Origins in the Mediterranean and the Near East, Crown, New York, 1966, p. 238.

²Winter, F.E., "Tradition and Innovation in Doric Temple Design I, West Greek, AJA 80, 1976, p. 142.

³Dombart, col. 270.

⁴Dombart, col. 270.

open to new influences, free from the restrictions of home, and forced to use and exploit the new building materials at hand. In any case, there was a mass exodus precipitated in part by the Persians just a half decade before the first examples (extant) of a rash of temples was built in the colonies (Selinus D, Paestum: 'Basilica', etc.) (See Appendices I and III.) Virtually all these temples had strong entasis.¹

¹A modern suggestive theory on the possible conception of entasis in Egypt also considers and indeed, accounts for the subtle differences in Greek entasis by relating them to Egyptian origins. Livio Catullo Stecchini, an archaeo-astronomer and metrologist with doctorates in Roman Law and in ancient history (from Italy and Harvard), has developed his theory that the ancients were greatly concerned with the problems of describing the curvature of the earth in mathematical terms and of projecting a curved surface on a flat map. He sees in the Great Pyramid of Khufu or Cheops - and in Herodotus' words - proof that the Egyptians succeeded in projecting a quadrant of the earth's surface (northern hemisphere) onto the side of a pyramid, in a more sophisticated way than did the Babylonians in the great ziggurat at Babylon, or Mercator in his much later projections. Stecchini further develops his theory to show that the column's shape was nothing more than a cylindrical projection of a map of Egypt and that the unique hyperbolic curve in the columns of the Parthenon indicates that the columns project a map of the world from the equator (at the base) to the latitude of Athens at the top. The varying curvature in between presumably represents the extension of the system of meridians to east and west. This theory is dealt with in more detail in Appendix V of this study. It comprises the Appendix proper to Tompkins, Peter, Secrets of the Great Pyramid, Harper & Row, New York, 1971. Mention of entasis and the Greek Doric column is, unfortunately, almost incidental. The theory, nonetheless, deserves more consideration than it has received from classicists, as does Stecchini's theory of the relationship of Egyptian, Mycenaean and Greek foot measurements.

West Colonial Temples with and without Entasis
(arranged chronologically)

1. SYRACUSE, Apollo
2. SYRACUSE, Zeus
3. SELINUS, C
4. SELINUS, D
5. PAESTUM, Basilica
6. SELINUS, F
7. ACRAGAS, Asklepieion
8. PAESTUM, Ceres/Demeter
9. METAPONTUM, Tavole Paladine
10. ACRAGAS, Heracles
11. SYRACUSE, Athena
12. SELINUS, E
13. PAESTUM, Poseidon
14. ACRAGAS, Hera Lacinia
15. ACRAGAS, Concord
16. SEGESTA (unfinished)

		X		
			X	X
X				
X				
		X		
X				
X				
X				
			X	
X				
			X	
X				
	X			
with	probably with	uncertain	probably not	positively not

(see p. 29 n.2 for details)

If we cannot say exactly where or when entasis was first employed as a refinement in the Greek world, we can say that once the Greeks on the mainland made it their own they did so with considerably more subtlety than did their Egyptian predecessors or contemporaries and, indeed, than did their later western imitators. This earliest of refinements in the Greek temple is the only one adopted 'wholeheartedly' by the Ionians and used widely after the fifth century B.C.¹ For this reason it is given priority in this study, and the few other pertinent refinements are discussed in relation to it.²

¹Coulton, GAW, p.111.

²Observations regarding the chart on page 28:

- a) All information is from Koldewey and Puchstein who also include the Hera Sanctuary at Croton (though only one damaged column remains)(Dinsmoor, AAG, p.110), and the Temple of Castor and Pollux at Acragas (which Dinsmoor dismisses as picturesque and artificial because it was rebuilt probably from pieces of more than one temple and not even in the right place)(AAG, p.112).
- b) Attention is drawn to the 12th and 14th entries, which, though it is uncertain they had entasis, are in places where they had a precedent.
- c) Individual page references to sources are in the complete list of temples with entasis (Appendix III).
- d) The paucity of references to mainland or eastern Greek temples (beyond repetition of Penrose's contribution of six measured columns) makes separate charts for the mainland and the East redundant.
- e) Omitted entirely from this list (by K&P, Goodyear and Dinsmoor: Appendix I) are temples at Velia, Hipponium, Caulonia, Gela, Camarina, Megara Hyblaea, because they "do not have peculiarities requiring special mention." (Dinsmoor, AAG, p.110).

3. General Observations on Entasis

Ideally, one should compile all available information on entasis and relate the findings, facts and figures to our chronological charts in the Appendices. One might expect to trace the development of entasis - and other refinements - in time and in place. But the information available is woefully inadequate. One should have the column dimensions, radius, taper, the type of curve, its coordinates, amount and location of maximum entasis and its possible relationship to radius, semi-diminution, height of shaft, arris width, etc. Yet virtually nothing exists in available texts beyond the observations of Koldewey and Puchstein and the measurements of Penrose (to whose list Dinsmoor added a seventh column).¹

An example of the trivia follows: The entasis of some early columns of the Heraeum at Olympia (c 590) is 1/140 of the column height,² at Paestum, in the Basilica (c530) entasis was actually $2 \frac{1}{8}$ "³ or 1/120 of the shaft while in the Temple of Athena (Demeter, Ceres) (510) it was 1/160 of the column.⁴ This information is useless without other details; it suggests no pattern - no development. Penrose

¹Dinsmoor, AAG, p.169.

²Coulton, GAW, p.176.

³Dinsmoor, AAG, pp.94,169.

⁴Coulton, GAW, p.176.

gave us more complete information for the columns he measured,¹ but it suggests no pattern or development either. It seems that each architect somehow arrived at a degree of entasis which was somehow related to the column height and/or other dimensions of the column or building. Nor were ratios simple and even - a fact complicated even further by the fact that the Doric foot might have been used in one place and an Ionic foot in another; geographical and racial factors have to be taken into consideration too.²

We can say that entasis in the Periclean period was so subtle that it was undetected for more than two thousand years. We can say that entasis was somehow related to column size, and that shorter columns (under twenty feet, generally) did not have entasis.³ We know that the maximum swell never exceeded the column diameter and that it hovered about the one-third mark in the best columns. Finally, we can note that Ionic architects used entasis in such a subtle way that Penrose himself, who went looking and measuring for it, failed to perceive it in the Ionic features of the Propylaea.

¹This information has been made into a chart on page 64.

²Dinsmoor, AAG, pp.54-55

³Ironically, it is columns of this size and smaller that feature entasis in New England, Loyalist Ontario and even in the Ottawa Valley.

4. The Nature of the Curve and Conics

The swelling curve of entasis has been variously described as the arc of a circle,¹ a hyperbola,² a parabola,³ an ellipse,⁴ a conchoid of Nicomedes,⁵ or the vertical projection of a helix,⁶ which is the quadratrix of Tschirnhausen or perhaps of Hippias, though it is known as the quadratrix of Dinostratus.⁷ Entasis has also been described as a combination of curves,⁸ and while it is admitted that other curves may have been used, my own research has shown no evidence or mention, for instance, of the catenary curve so favored by modern architects. It is obvious that some consideration of the properties of these curves is in order.

¹Dinsmoor, AAG, p.168.

²Penrose, p. 42; Robertson, GRA, p.117; Dinsmoor AAG, p.168

³Robertson, GRA, p.117.

⁴Penrose, pl.47.

⁵Penrose, pp.40,41.

⁶Vignola, PlXXXI.

⁷Stevens, Gorham P., "Entasis on Roman Columns", Mem. Amer. Acad. Rome, IV, 1924, p.126. This invention is sometimes attributed to a late Renaissance person, to a pupil of Plato, or to a contemporary of Socrates. It may have been known to pre-Parthenon builders.

⁸Choisy, Auguste, Vitruve, vol.I, p.147; vol.IV, Pl.34, Fig.2.

The curve's requirements

In spite of the fact that Vitruvius credited the Greeks with using entasis and in spite of the fact that a) no Roman column is without it¹ and b) there was a continued tradition in using it from Roman times to this century, it was not until the 19th century that entasis was 'discovered' in Greek mainland temples.² We are safe, then in saying that the entasis curve was almost a straight line in Periclean temples. We also know that the curve had to be such that it could be applied to columns of varying dimensions in the same building(s). We can likewise assume that the curve could be easily laid out or calculated and that the practice was learned from architectural treatises now lost to us, or from oral tradition and architects scratching diagrams in sand scattered over the floor.³ It is also reasonable to assume that some simple device or diagram might be used to 'telescope', as it were, the pertinent information into a small portable format.⁴ The conic, the vertical

¹Stevens, ERC, fn.p.121; Robertson, on the other hand says it was merely 'common', Robertson, GRA, p.116.

²It had already been noticed in the colonies but ascribed to Roman undercutting.

³An excellent picture is painted in words in G.R. Levy's Plato in Sicily, Faber and Faber, London, p.28.

⁴It is unlikely that paper was used for plans or computations because a single sheet cost the equivalent of a workman's wages.

projection of a helix and the conchoid are the curves which best fulfill these conditions of the entasis curve. There follows a discussion of the properties of each curve, how it can be applied to the column, tested and identified.

Conics illustrated

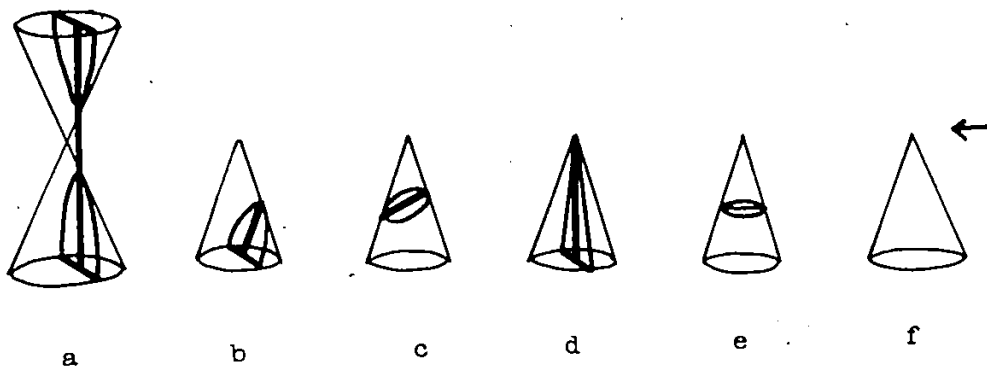


Fig. 6.. Conics

The hyperbola: the cutting-plane cuts both nappes of the cone, as in figure a.

The parabola: the cutting plane is parallel to the straight line of the surface of the cone, as in figure b.

The ellipse: any other section, as in figure c, except figure d: one cutting the end parallel with the axis of the cone.

figure e: one perpendicular to the axis of the cone.

figure f: one cutting only the vertex.

It is obvious that the 'curve' in figure d is a straight line, that the curve in figure f is of no practical use either, and that figure e gives a circle - a special kind of ellipse with major and minor axes being equal.

Characteristics of the conic making it useful in establishing the entasis curve

On pages 33-34 we saw that the entasis curve must be a) almost straight, b) applicable to columns of varying dimensions, c) easily laid out, calculated and taught, and d) capable of reduction and expansion through diagrams or simple devices. The conic curves satisfy these criteria; e.g., while the diagram below is of a series of hyperbolas, the proposition it shows holds true for the parabola and the ellipse.

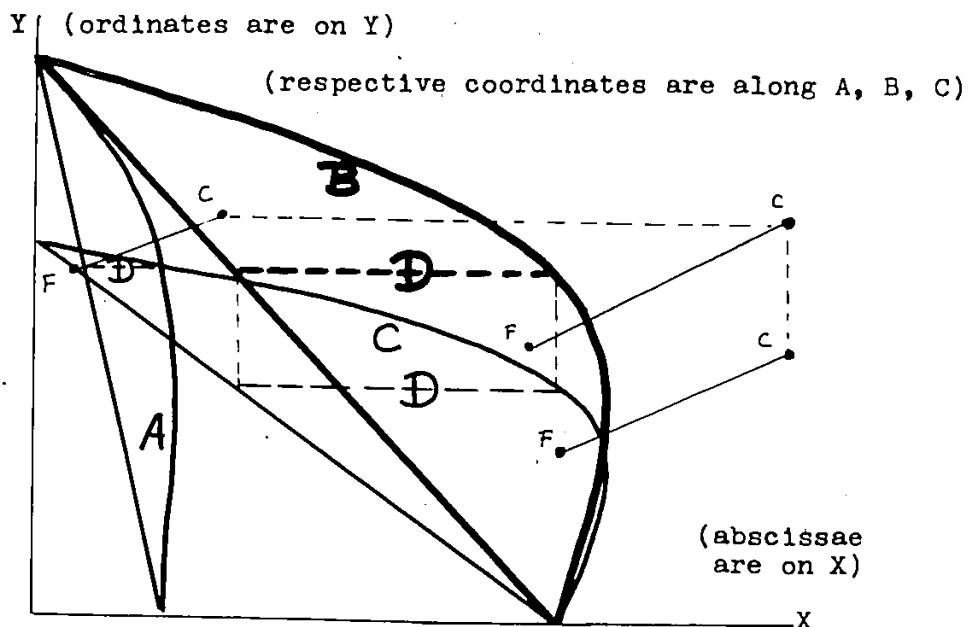


Fig. 7.

The hyperbola A, in Figure 7, may be redrawn with the abscissae (here multiplied by 4) at any new scale B. B, in turn, is redrawn at a new scale C (with ordinates reduced to $2/3$ their original dimensions. YET THE CURVES B AND C REMAIN THE SAME KIND OF CONIC AS THE ORIGINAL A.

Note also:

a) in redrawing the conic with the abscissae at a new scale (A to B): i) the maximum horizontal distance travels both horizontally and proportionally to the new scale, and

ii) in the case of the hyperbola and ellipse, the center as well travels horizontally and proportionally to the scale while the angle of the axis of the conic, the apices, and the foci are all changed.

Similarly,

b) when the conic is redrawn with its ordinates at a new scale (B to C):

i) the maximum horizontal distance travels vertically and proportionally to the new scale, and

ii) in the case of the hyperbola and ellipse the center as well travels vertically and proportionally to the new scale while the angle of the axis, the apices, and the foci change.¹

¹Except when the axes of the conic are parallel to the co-ordinate axes in which case the angle of the axis of the conic remains the same and the apex travels proportionally to the new scale and parallel to the co-ordinate axes.

Attention is drawn to D in the illustration. D is the maximum horizontal distance. Because of the characteristics of the conic we can identify D also as the maximum horizontal entasis. It follows, therefore, that we can use our scaled down and distorted small curve to convey all the actual information and measurements we require in the entasis curve.

He who would study the entasis of a column must first measure it and plot the curve on a reduced and exaggerated scale. Then he must identify the curve and, perhaps, deduce how it was plotted in the first place. (Appendix VI shows drafting techniques used in making some curves; its purpose is to illustrate the variety and relative simplicity of graphic approaches.) We now proceed to a graphic investigation of conic curves with the aforementioned purpose of identifying types.¹

¹The diagrams that follow have been copied or adapted from Stevens, G.P., "Entasis in Roman Architecture", Mem.Amer.Acad.Rome, IV, 1924, 128-137. A more graphic presentation of the characteristics of conics can be had by screening the Film Associates 16 mm movie: Conic Sections, produced by St. Bosustow.

The locus of the middle points of every system of parallel chords of a conic is a straight line, but...

...in the parabola the loci are parallel to the axis of the curve (Figure 8):

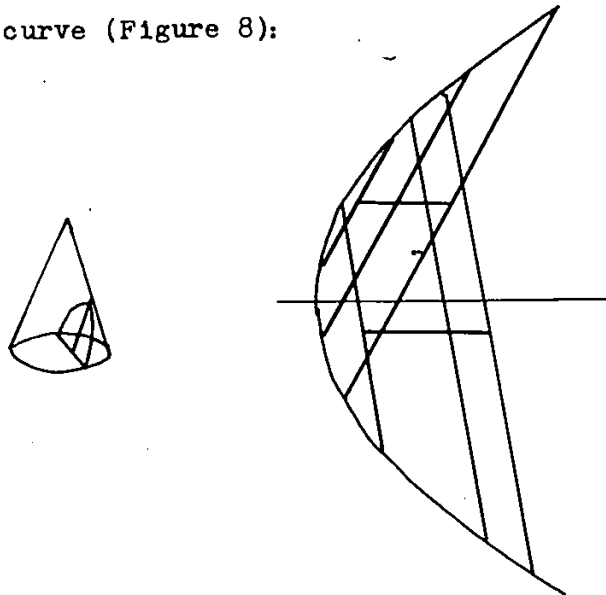


Fig. 8

...in the ellipse they pass through a point (the center) within the curve (Figure 9):

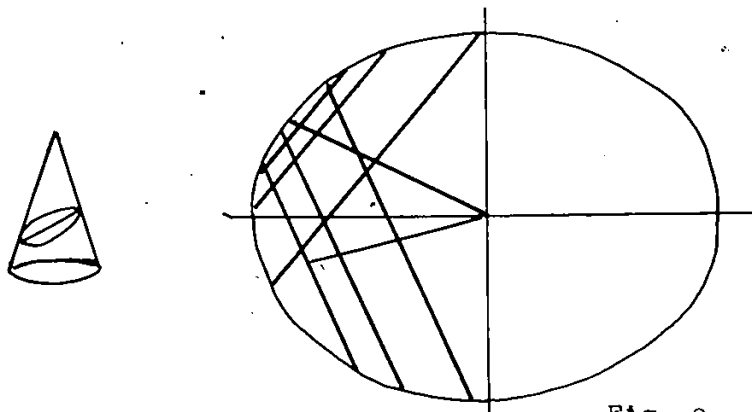


Fig. 9.

...in the hyperbola they pass through a point (the center) which lies outside the curve (Figure 10):

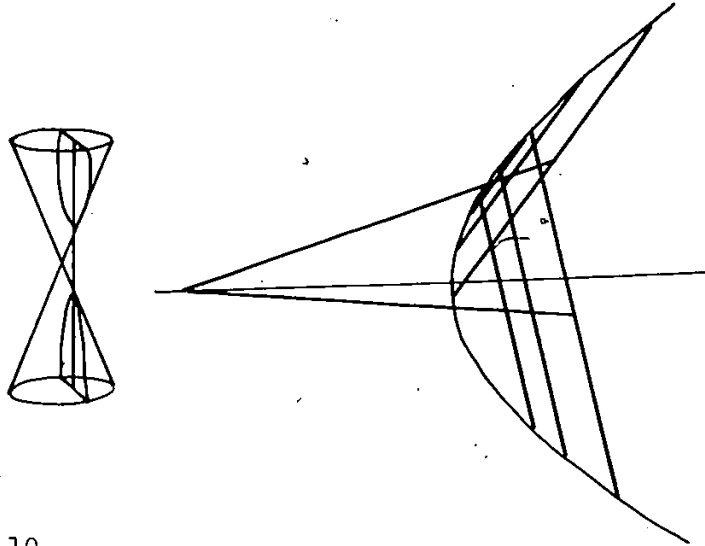


Fig. 10.

The parabola, ellipse and hyperbola are possibly the curves used by the Greeks though they were **to be** invented only after the Periclean masterpieces on the Acropolis were erected. Two other conic-like curves must be considered: the vertical projection of a helix and the conchoid of Nicomedes.

The vertical projection of a helix

In the diagram the vertical axis coincides with the axis of the column (Figure 11):

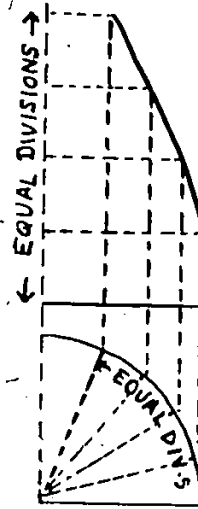


Fig. 11

This curve may be used for cigar-shaped columns (non-Greek) in which the maximum entasis and maximum radius of the column coincide. The curve may also be redrawn with both its abscissae and its ordinates at new scales without changing the kind of curve. As in the conic, the entasis, or maximum horizontal distance, in the redrawn curves follows the same laws.

The graphic test for vertical projections of a helix

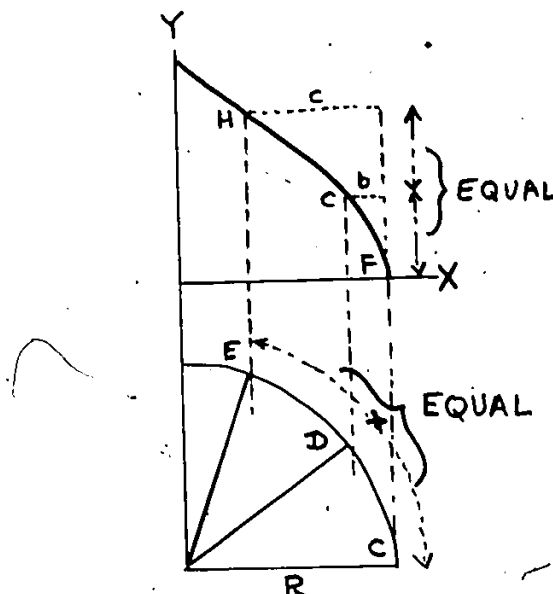


Fig. 12.

This test is simple, but, unfortunately, it does not hold true for large columns and an unwieldy three-page mathematical method is employed. It is attached as Appendix VII.

This is not to suggest that the helix was not used by the ancient Greeks, but Penrose makes no mention of it and Vignola is the first to introduce us to it. It must also be remembered that the difficulty is not in applying the curve to entasis; this can be done easily in a reduction diagram, or with measurements made on a column drum head. The difficulty is in testing fully. The mathematics sometimes over-awe one. It is obvious that the Greeks had no such problem testing for the nature of the curve. They knew exactly what they wanted, the properties of the curve, its nature, its dimensions. If they tested at all, it was for exactitude to specifications. For this they would use templates of sorts.

The Conchoid of Nicomedes

The conchoid of Nicomedes can easily be described by a machine, as in Figure 13a:

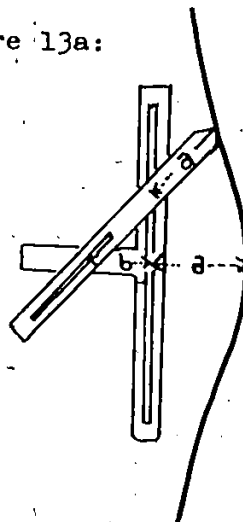


Fig. 13a

The curve is otherwise laid out as shown below:

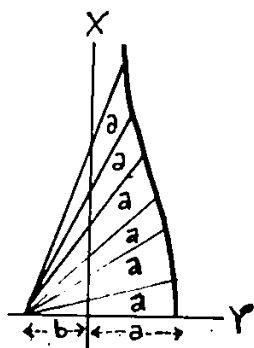


Fig. 13 b

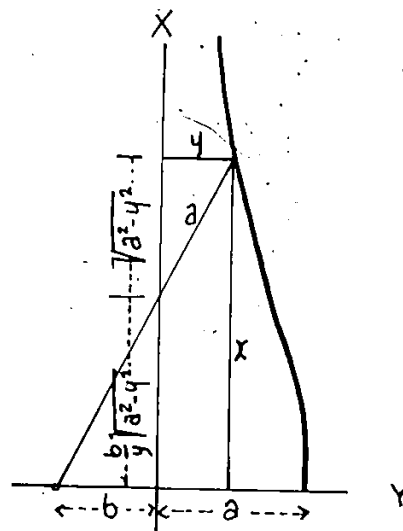


Fig. 13 c

The conchoid does not remain a conchoid when redrawn with either its abscissae or ordinates at new scales (though the maximum horizontal distance or entasis in the redrawn curve follows the same laws as the redrawn conic or vertical projection of a helix). In any case, a graphic test is therefore not possible and a lengthy and involved mathematical test must be used. (Appendix VIII)

The Greeks may not have used the conchoid in their columns. Penrose could not apply it in his study of the Athenian columns.¹ Stevens allows that it is used in two of the eight columns he examined: in the Basilica of Trajan (about 113 A.D.) and in the inside order of the Pantheon (time of Hadrian, not after 138 A.D.). This use by the Romans seems natural enough because the inventor of the conchoid was born about the time of Julius Caesar, ca 100 B.C. Goodyear does not concern himself with the types of curves in his monograph.

In any case the conchoid must be considered because a) it is a Greek invention, b) it may have been in use for centuries before it was 'invented'² and c) it does, after all, fall within the entasis curve requirements.

¹Penrose, pp.41, 49, n.1.

²"We know today that all the factual mathematical knowledge which is ascribed to the early Greek philosophers was known many centuries before, though without the accompanying evidence of any formal method which the mathematicians of the fourth century would have called a proof." Neugebauer, O., The Exact Sciences in Antiquity, Dover, New York, 1969, p.148.



From a consideration of the properties of the conic curves, one must now move to analysis of the major methods of measuring and plotting the curves of extant columns for study purposes.



Measuring and Plotting the Entasis Curve for Study

There is no reason to believe that Greeks themselves plotted the entasis curves as we must. It is academic whether or not they could do so. Their great individuality would mitigate against their doing so merely for the sake of copying. An analysis of the statistics available, especially Penrose's projections to a uniform scale (my p. 67) suggest that each architect arrived at his own formula in his own way, and/or that he had done so from consideration of a host of variables that made his specific curve suitable to the one site and no other. He may even have used a personal or ad hoc formula, for beyond the similarity in curve types, eg. hyperbola, there seems to be no uniformity in ratio, proportions or dimensions (see also page 64). But if a Greek did want to plot the curve of an existing column, he may well have proceeded more or less as did Penrose and Stevens, and as we must.

Let us assume that the column is well preserved, so that no compensations or adjustments need be made (for shifting, etc.) Penrose's diagrams of Athenian columns are proof enough of the extra work that 'anomalies' due to wear and tear can cause.

A steel wire is stretched near the column. It must be on the same plane as the axis of the column; it need not be

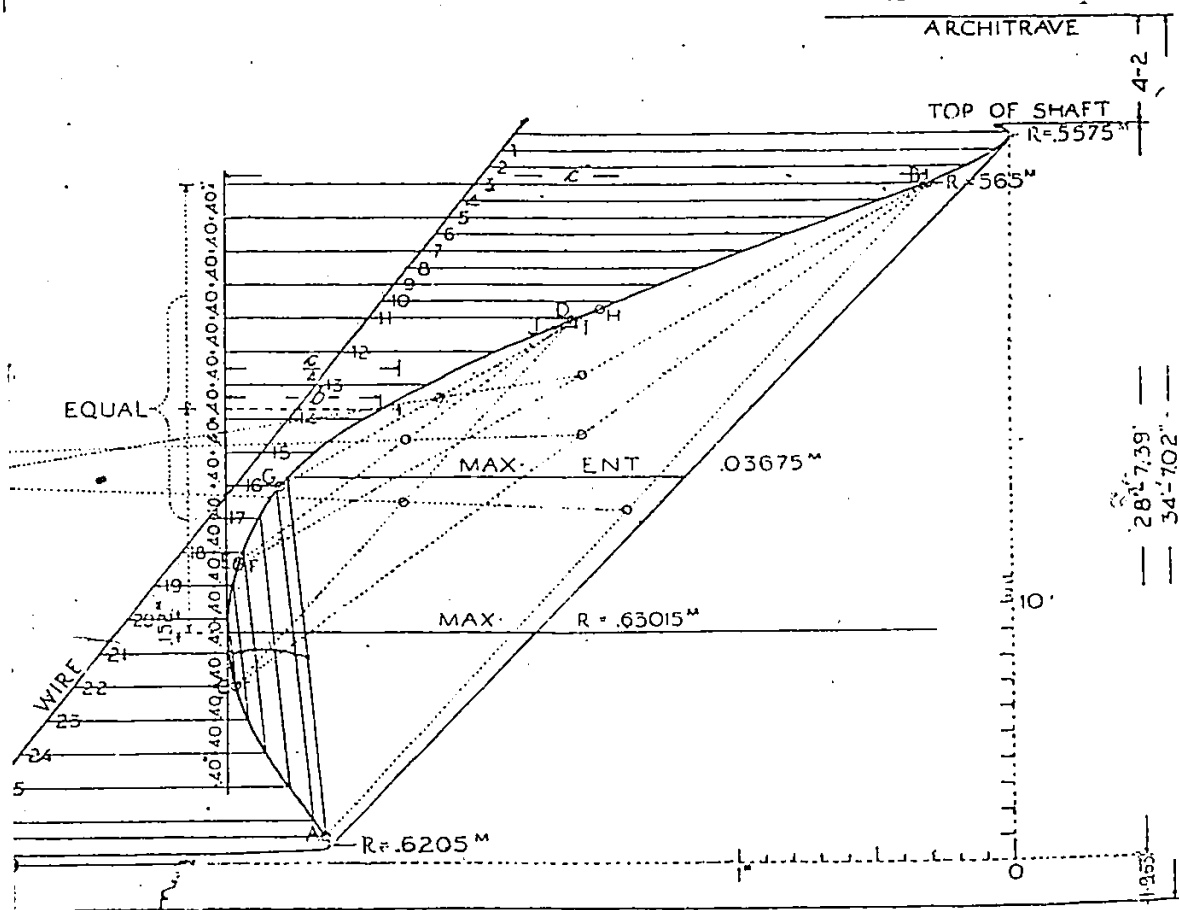


parallel to the axis of the column or to the chord of the curve.¹ The taut wire is a reference point from which to measure the curve of the column. Diameters at top and bottom of the column are determined using callipers or circumference measurements. The horizontal distances from these points (A and B) are noted and then as many other horizontal distances as possible are recorded. In each case a corresponding vertical distance is also recorded. Readings can be taken with the aid of a micrometer to the twentieth of a millimeter. The more measurements, the more accurate the plotted curve.

One may proceed as did Penrose and record mathematical data while exaggerating the entasis curve slightly and scaling up the horizontal distances. Penrose reduced all his drawings to one-fiftieth their normal size (pages 50 to 63 of this study). The curve produced can be seen clearly and is not a great distortion on reality. Or one may proceed as did Stevens (Figure 14, Appendix X). He reduced all his columns to the same height and proportional horizontal scale so that the curves are much more exaggerated but still true to kind and easier to compare with others.

¹Stevens uses this technique. Penrose went one step further and aligned his reference wire so that it was parallel to the central axis of the shaft whenever possible.

Stevens' studies of the Roman entasis are the only ones available in this uniform scale and format. Accordingly, they are reproduced on loose acetate sheets in an envelope at the back of this study, so that they can be removed and superimposed over one another for more critical analysis (Appendix X). One of the series is shown below:



Entasis, Column, Forum of Trajan.

Fig. 1A.

from Stevens, ERC, p.137

This is not the only system that can be used, but a comparison with other diagrammatic and mathematical representations will show that - if one makes an effort to understand the drawing conventions - the system is superior.

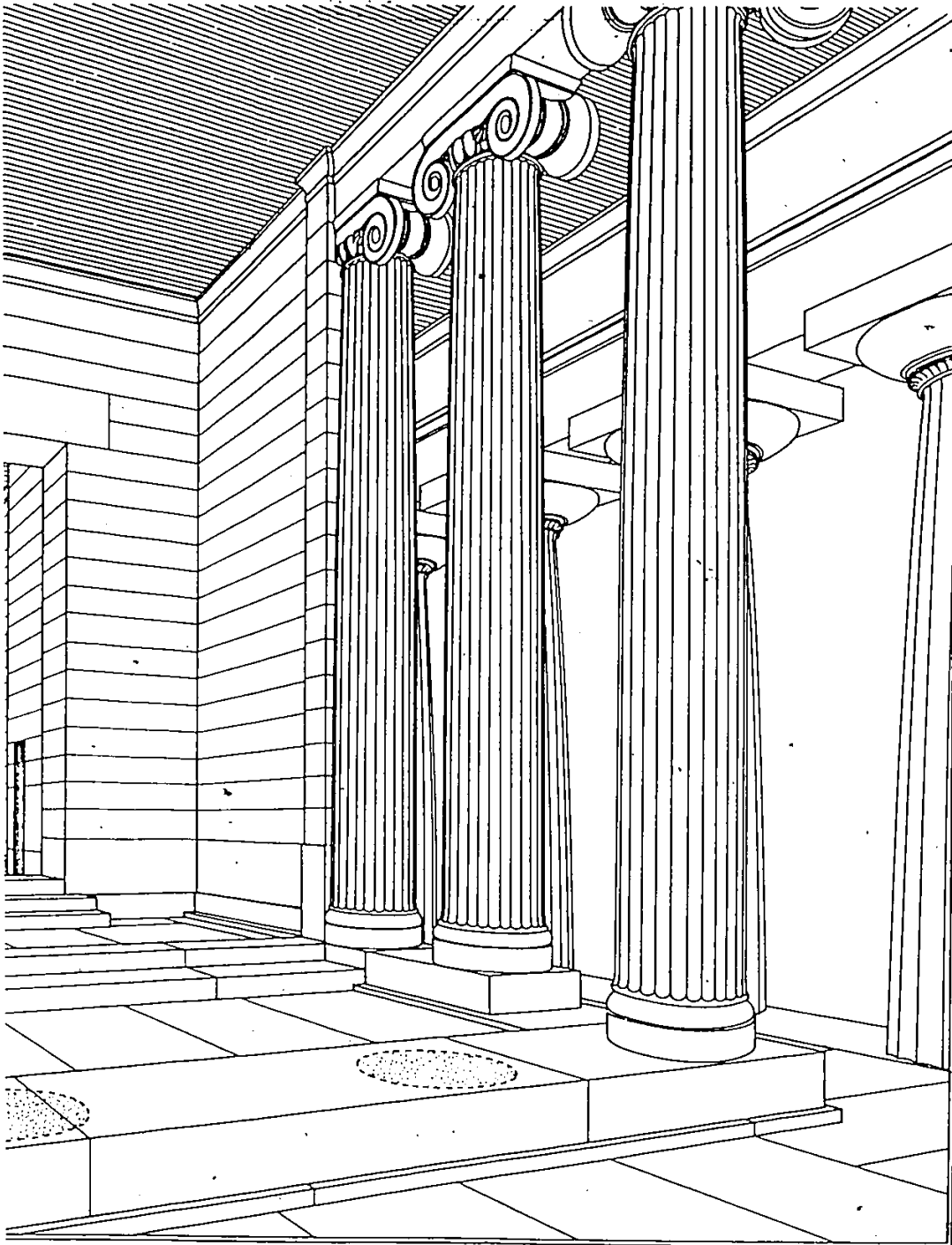


Fig. 15. a) Representation of entasis: a) graphic reconstruction
 The Temple of Athena at Paestum (illustration by Krauss) is
 here presented without comment; the viewer may miss the entasis
 entirely. (Die Tempel von Paestum, Pl.45)

Fig. 15. b. (reproduced from Udhe, C.)
Information at left is presented using
mathematical measurements.

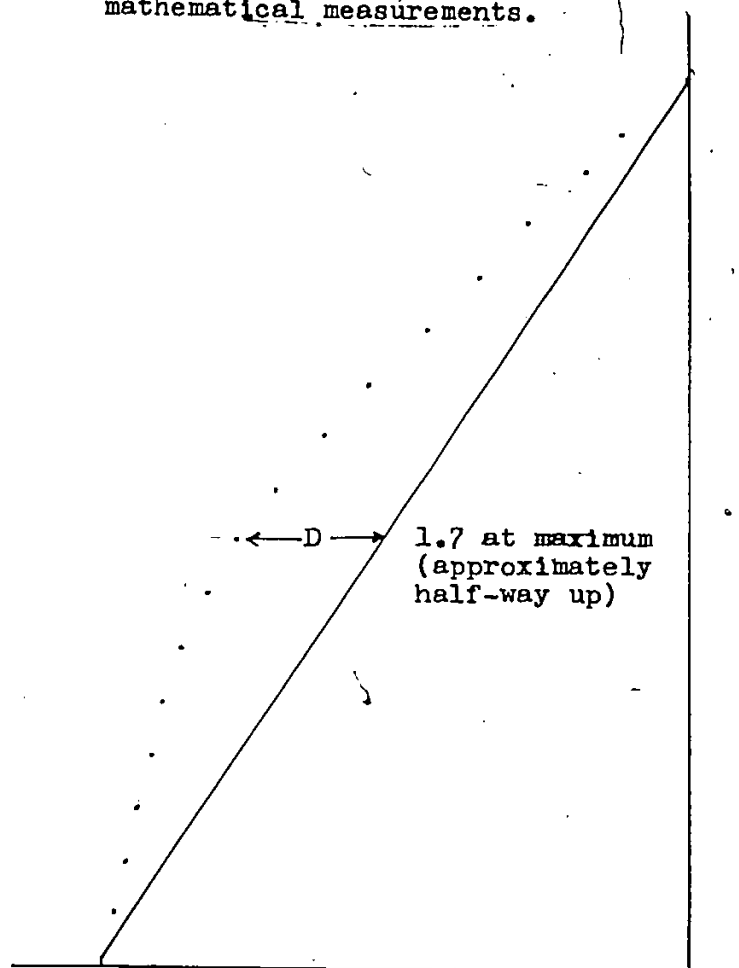
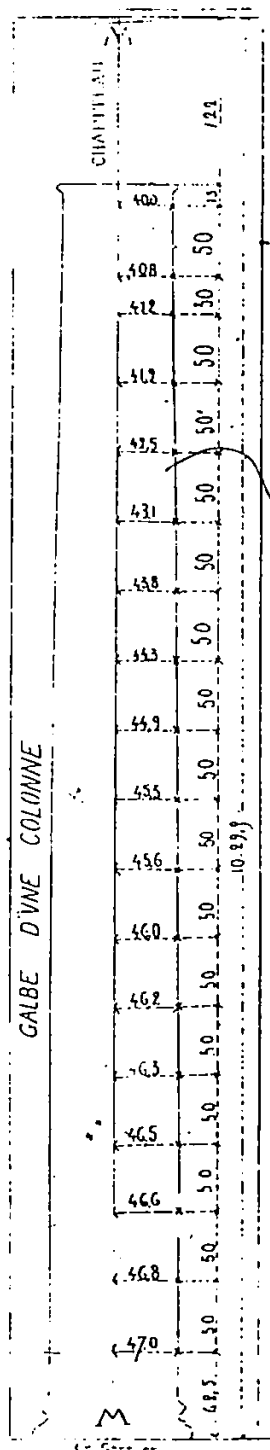


Fig. 15. c. (by author)

The information in the column at left
is plotted on ordinary note-book paper
from a vertical with a convenient scale.

5. Penrose's Diagrams

Penrose gives measurements and detailed information for the entasis in only six columns.¹ This information is compiled in chart form on pages 64 and 67. The essentials of the illustrations (and comments on each) follow:

The Parthenon	p. 51
The Propylaea (large)	55
(small)	56
The Erechtheum	58
The Theseum	60
Zeus Olympius	62

Attention is drawn to the detailed information available and to the fact that all the columns are one-fiftieth actual size and turned marginally to show full diameters. Offsets are given and shifts are noted; however, reduction to the same size for all columns for comparison purposes is feasible.

¹Penrose does give measurements for a second Parthenon column in his Appendix, p.121.

Heights
Table (1)

*Parthenon. — Entasis of Columns.
From the Northern of two central columns, East Front.*

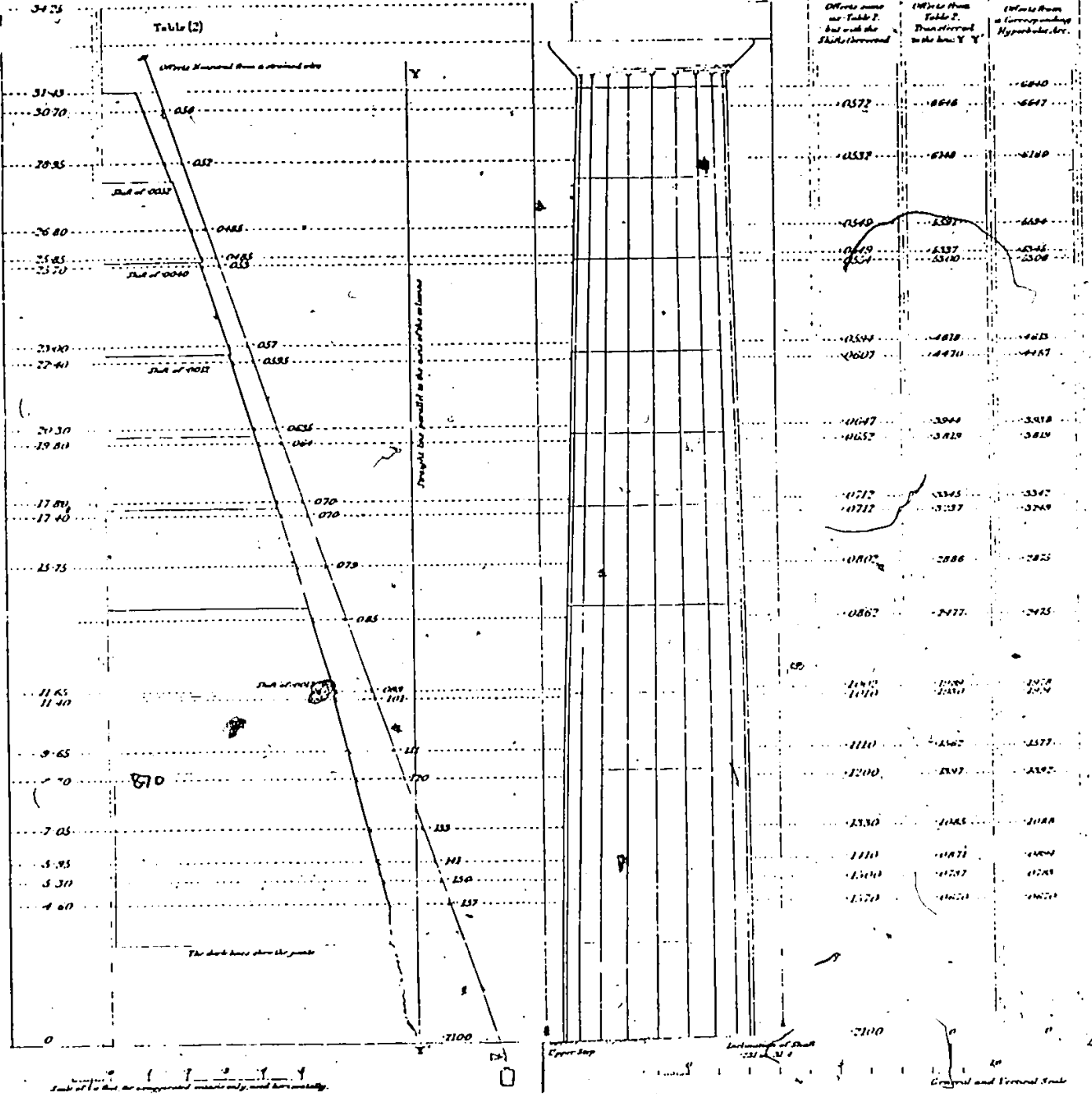


Fig. 16

(Reproduced from Penrose, Pl. 14)

POOR COPY

The Parthenon Column by Penrose

Measurements were taken from the Northern of two central columns, East front. The entasis curve in the Parthenon is unique: the vertex is outside the column and not considerably above the base but two diameters below the stylobate. Attention is drawn to the line Y Y' in each diagram by Penrose. It is either the vertical axis passing through the center of the approximating hyperbola or it is parallel to that line. In five cases it is oblique or inclined. Only in the Parthenon is it vertical. The entasis curve decreases continually with the height and the point of maximum entasis is lower than in the other buildings (with the exception of the entasis in the Temple of Olympian Zeus which was completed centuries after the Periclean age.).

The entasis curve is a hyperbola. The rectangular axes of the figure are vertical and horizontal, i.e. parallel to the horizontal lines of the column. The principal line is 1 Attic foot, 1.0134 British feet. The constant ratio or excentricity is an integral number 30 to 1, with the radius of curvature of the hyperbola at the point coinciding with the base of the column being five times the length of the building.

Penrose concedes, after all this, that because the vertex is off the column, perhaps other curves could be fitted. And he admits that a conchoid could be applied

obliquely. Finally, the 'curve' is, in fact, not curved. That is, the drum sides are straight and only the top and bottom edges meet at points that are coordinates on the hyperbolic curve (which Dinsmoor thinks was a 'circular curve'.)¹ /

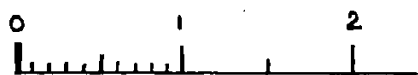
Penrose observes that the radius of curvature at the point intersecting the stylobate is 1143 feet, exactly five times the flank.² He also notes that a circle passing through the middle, upper and lower parts of the entasis arc produces a radius of 2280' or 10 times the flank. But does 1143 double to 2280?

At the risk of citing 'statistics, statistics, and damned lies' I would point out that there is a mathematical discrepancy in the above figures. One wonders too about the significance of taking three coordinates on a parabolic curve and projecting them into a circle, however large. This type of 'projection' loses a bit of validity when minute measurements are projected from the Parthenon and made to encompass all of Athens even unto the Piraeus. (A page from Gardner's book is attached as Appendix IX to show the extent to which the study has gone.)

¹Dinsmoor, AAG, p.168.

²Penrose, p.42.

Fig. 17.



Information from Penrose's table 4 plotted on differing scales as coordinates of the entasis curve. Blue line to left is measured from the page edge; red line to right is measured from the yy' line. Shifts are magnified in the larger scale, yet the line characteristics are retained.

Propylaea.

Entasis from Northern Column, Eastern Portico.

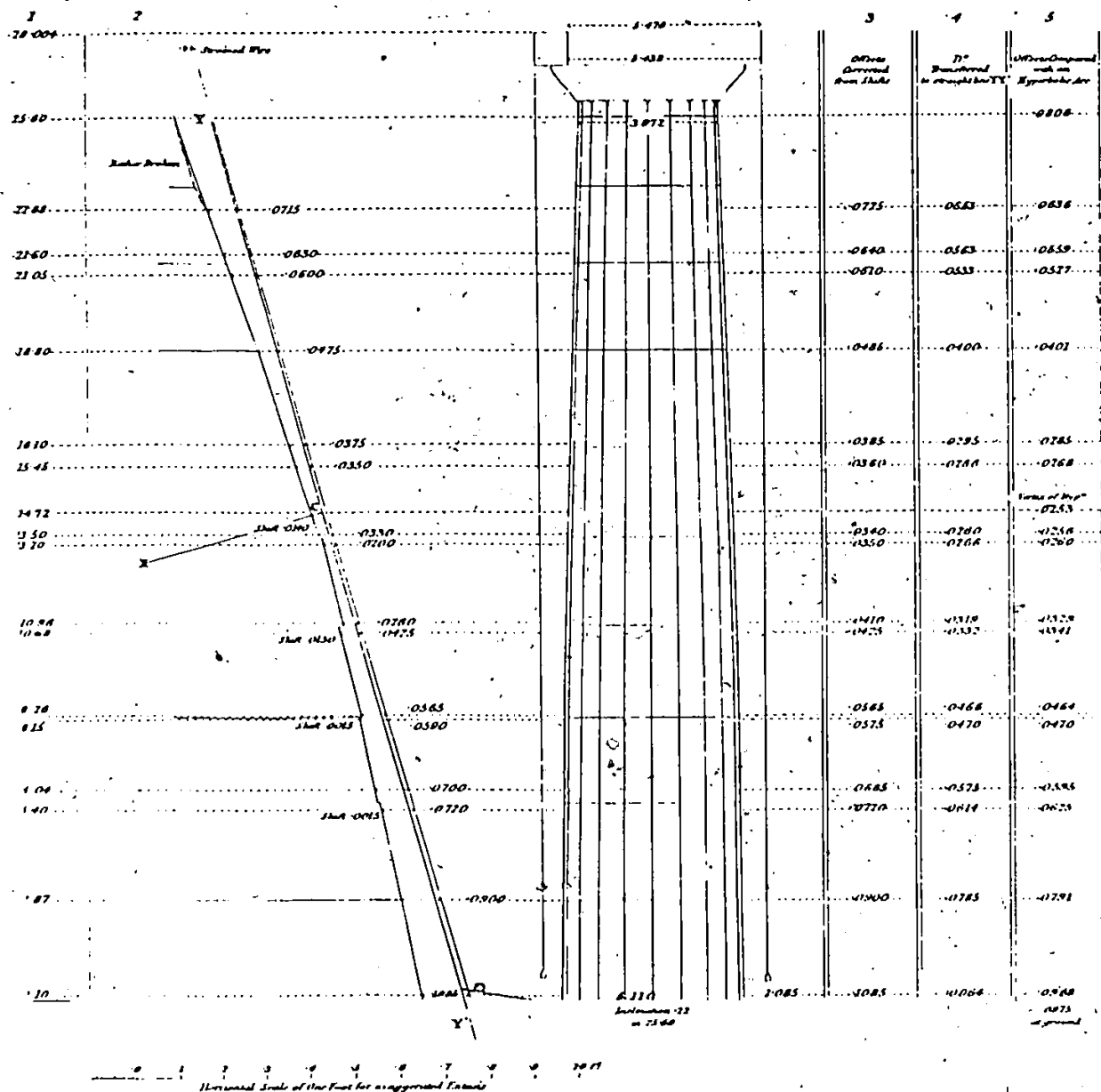


Fig. 18.

(Reproduced from Penrose, 33)

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Propylæa.

Small Order.

Entasis from Middle Column, North Wing.

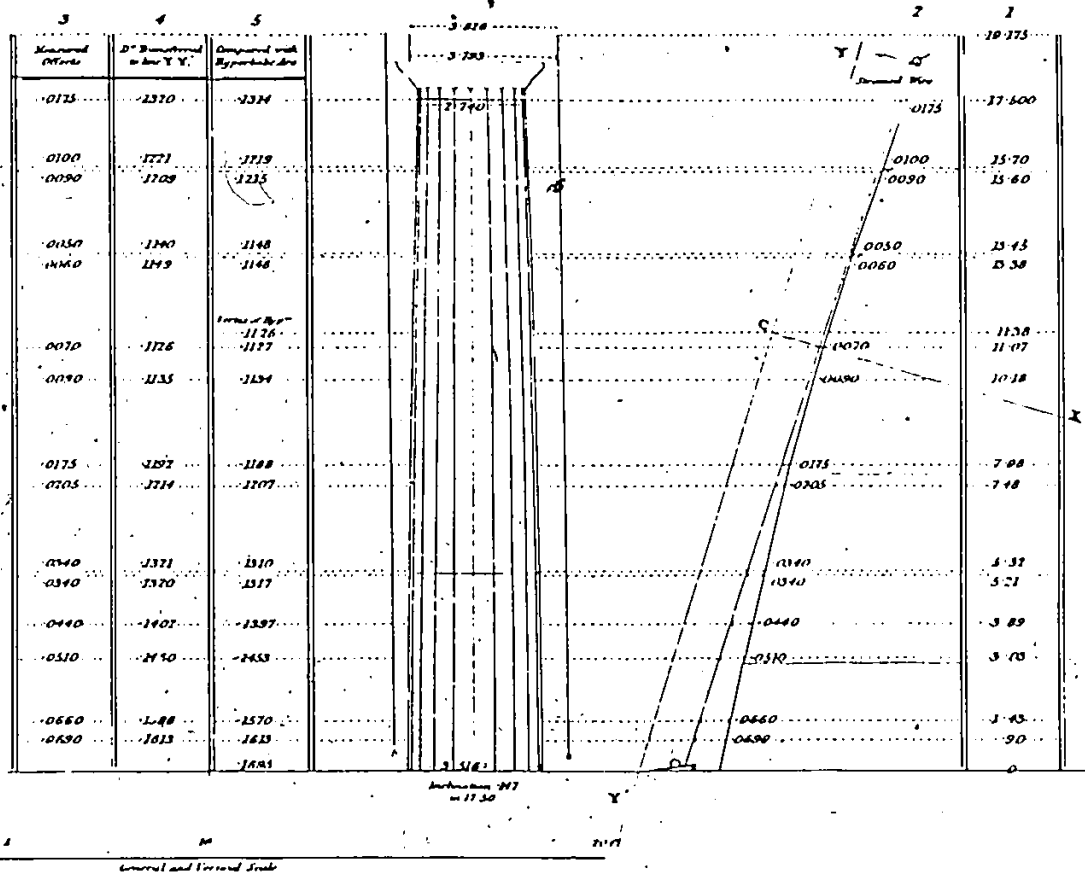


Fig. 19.

(Reproduced from Penrose, Pl. 33)

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The Propylaea Columns by Penrose

Measurements were taken from the Northern Column, Eastern Portico, for the large Doric column, and from the Middle Column, North Wing, for the smaller Doric Order. Penrose did not notice the very slight entasis (2 'units') in the Ionic order of the Propylaea.¹

The Y Y' lines are not vertical, but oblique and almost parallel with the chord made by the entasis curve. The curve itself is not ambiguous because the vertex is near the middle of the shaft.

The maximum entasis of the north column of the east portico is .0627 or one dactyl exactly (and the half-diminution is .57 or 9 dactyls). The smaller order has a proportional amount of entasis (it is .0343 or 1/11 of the half-diminution of .388) presumably because it was felt that a small column required less relative entasis than a larger one. The radius of curvature of the larger order of the Propylaea at vertex is exactly 569.2 (or half that of the base of the Parthenon columns).²

¹See page 64 for the chart grouping 'unit measurements'.

²Penrose, p.43.

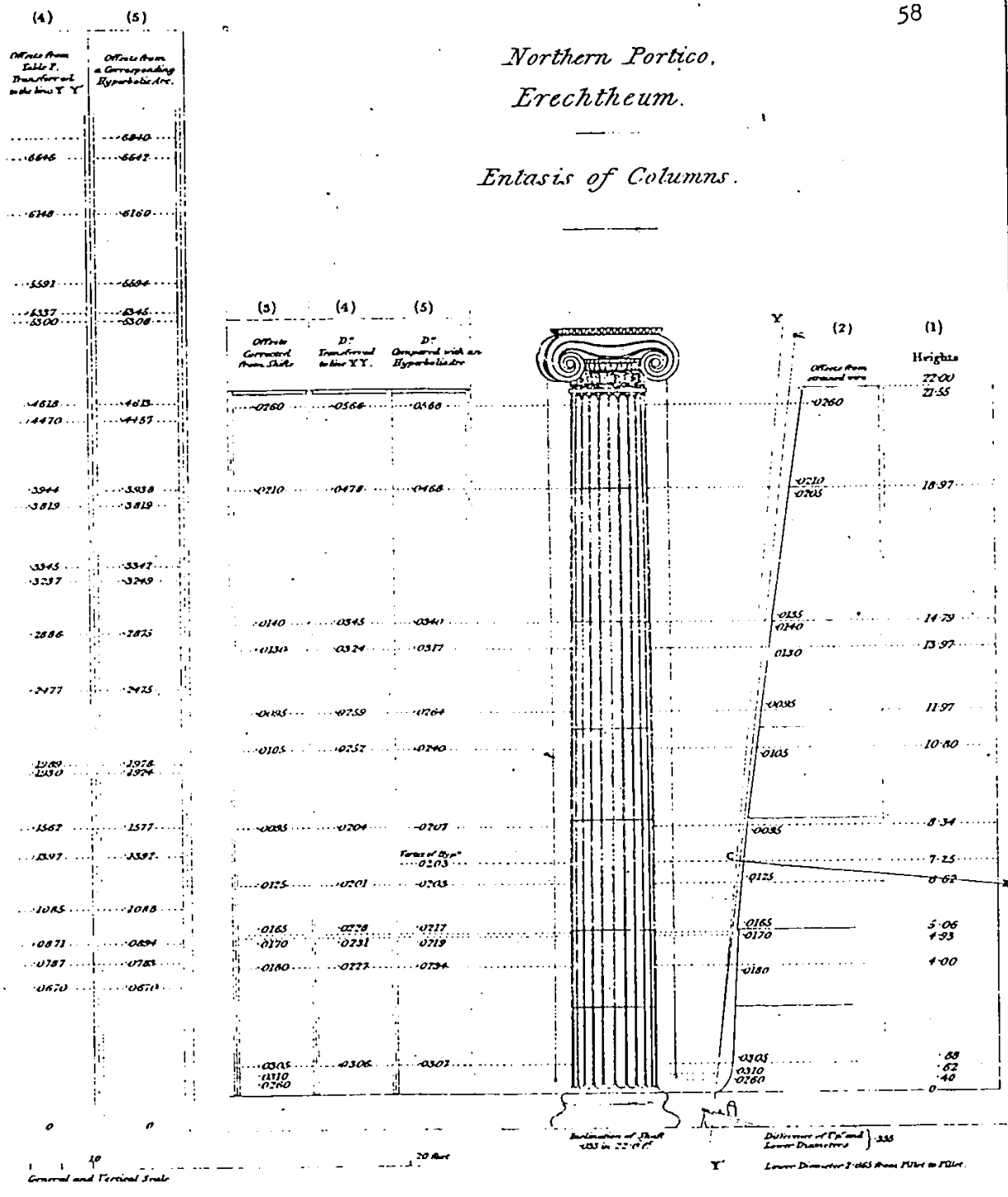


Fig. 20

(Reproduced from Penrose, Pl.14)

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The Erechtheum Columns by Penrose

According to Vitruvius III, 5, the entasis should be $.036^1$ in the north porch. It is only $.0195$, or $1/9$ of the half diminution of $.1775$.² Again, it will be noted that there is a slight discrepancy here. $.0195$ multiplied by 9 is $.1755$. The error is small, perhaps, but it is great by comparison with the other errors cited by Penrose. (Similarly, of course, $.1775$ divided by 9 is $.0197222$.)

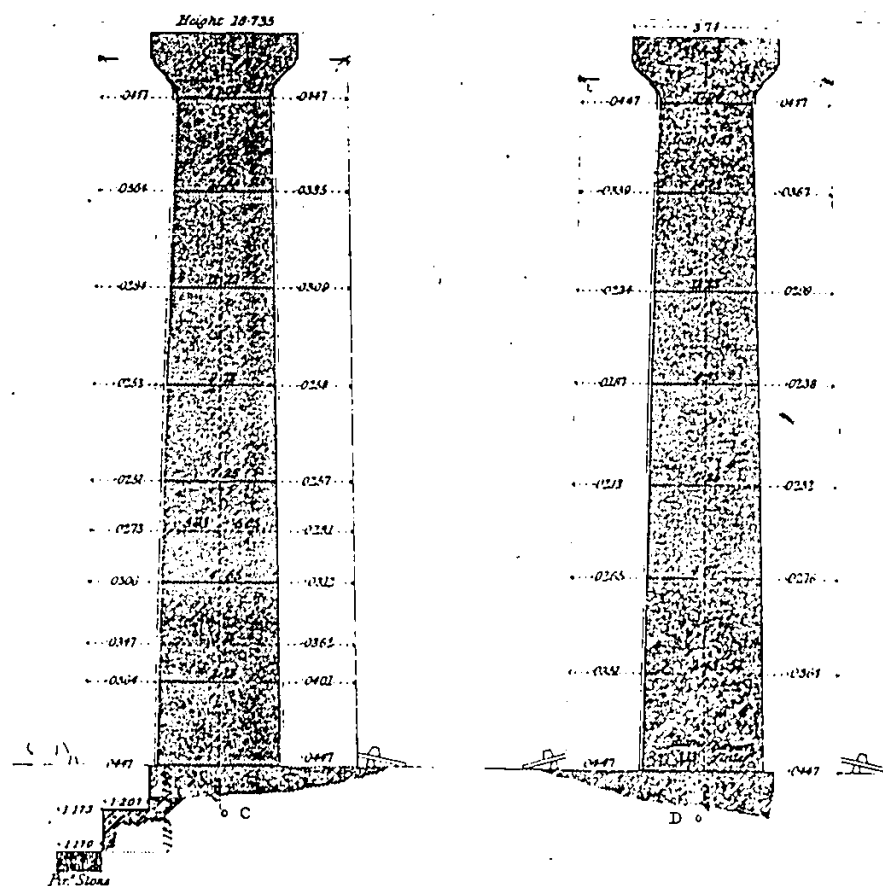
The entasis is very small and almost undetectable. It is $1/1080$ of the shaft, equivalent to an increment in curvature of $093/100$.³

¹Penrose, p.44.

²Penrose, p.41, 42.

³Penrose, p.107.

'Theseum' entasis according to Penrose



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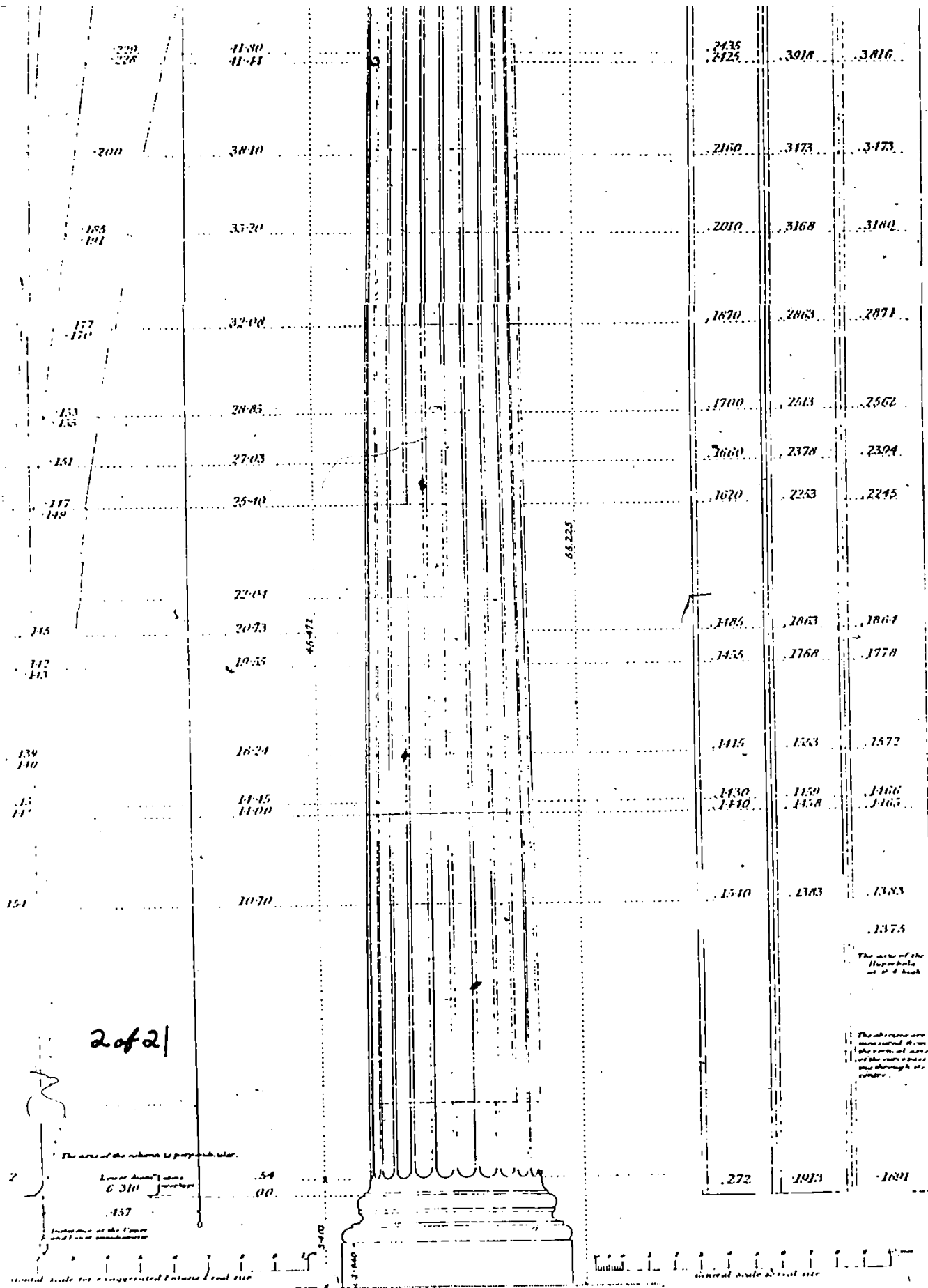
The Theseum (Hephaisteion) Columns by Penrose

Flute cusps were so damaged that two selected columns were measured from the (much less satisfactory) flute grooves. The offsets shown are the mean of four measurements; the greatest error is .0007 of a foot.

The semi-diminution in the columns is .3855, which is probably derived from the angle abacus, which is 3.856 across.

The entasis arrived at from the averaging of four measurements is .023. Penrose feels it was probably supposed to be $1/16$ of .3855, or .0241.¹

¹In which case, the error in the entasis would be almost twice his maximum error. Penrose does not suggest that his measurements might be wrong, or that masons' margin of error has to be considered.



The Column of the Temple of 'Zeus Olympius' by Penrose

The columns of this temple support in part the largest stone in construction in Athens - about twenty-three tons. Measurements were taken from a column (third from the east on the southern flank exterior) whose state of preservation, as far as entasis was concerned was only 'tolerably perfect'; but whose capital was remarkably preserved.

Entasis is not quite so 'beautifully regular' as in the Periclean temples and the hyperbola is suggested only 'with considerable probability' as the nature of the curve. Half-diminution is .457 and entasis is .118 or nearly $\frac{1}{4}$ of the semi-diminution which is almost exactly $\frac{1}{14}$ of the lower diameter.

This temple was completed, of course, in Roman times. According to Vitruvian formulae the diminution should be $\frac{1}{8}$ of the lower diameter and the entasis equal to the fillet of the flute, or .133. It is the only column measured by Penrose to have a profile perpendicular to the base in later Roman fashion; furthermore, Penrose sees a comparison with the entasis of the Pantheon at Rome given by Desgotez in Edifices Antiques de Rome.¹

¹ Penrose, p.39, 43-44.

6. Comparative Entasis in Terms of Units

Entasis is sometimes said to be calculated in terms of shaft length, lower diameter, full or semi-diminution, even width of arris. It is interesting to telescope the information Penrose gives on the six Athenian columns into a single chart to see if there is any apparent uniformity or development:¹

	Length of shaft exc. of Apophyge	Maximum entasis	Height of maximum entasis above stylobate	Height in terms of percentage of shaft	comparative entasis in 31.43 shaft	units	2 Ionic order (Propylaea) ²			
							entasis in terms of lengths of shaft	entasis in terms of lower diameter	in terms of semi- diminution	semi-diminution
E.	21.12	.0195	10.42	5/12	.029	4	1/1080	1/134	1/9	
T.	17.1	.023	8.7	1/4	.042	6	1/708	1/140	1/16	.3855
Pa.	31.43	.057	13.8	2/5	.057	8	1/552	1/110	1/12	.685
P.s	17.5	.0343	9.33	1/2	.0615	9	1/500	1/100	1/11	.388
P.l	25.6	.0627	13.75	1/2	.077	11	1/400	1/80	1/9	
ZO	43.70	.118	18.4	1/3	.084	12	1/382	1/56	1/4	.457

E - Erechtheum North; T - Theseum; Pa - Parthenon;
P - Propylaea East P (small & large); ZO - Zeus Olympius.

.0627 equal 1 dactyl (1/16 foot)

¹Penrose, pp.14, 37, 51.

²Dinsmoor, p.169. Dinsmoor accepts the units by Penrose and adds the Ionic Propylaea unit which was not perceived by Penrose.

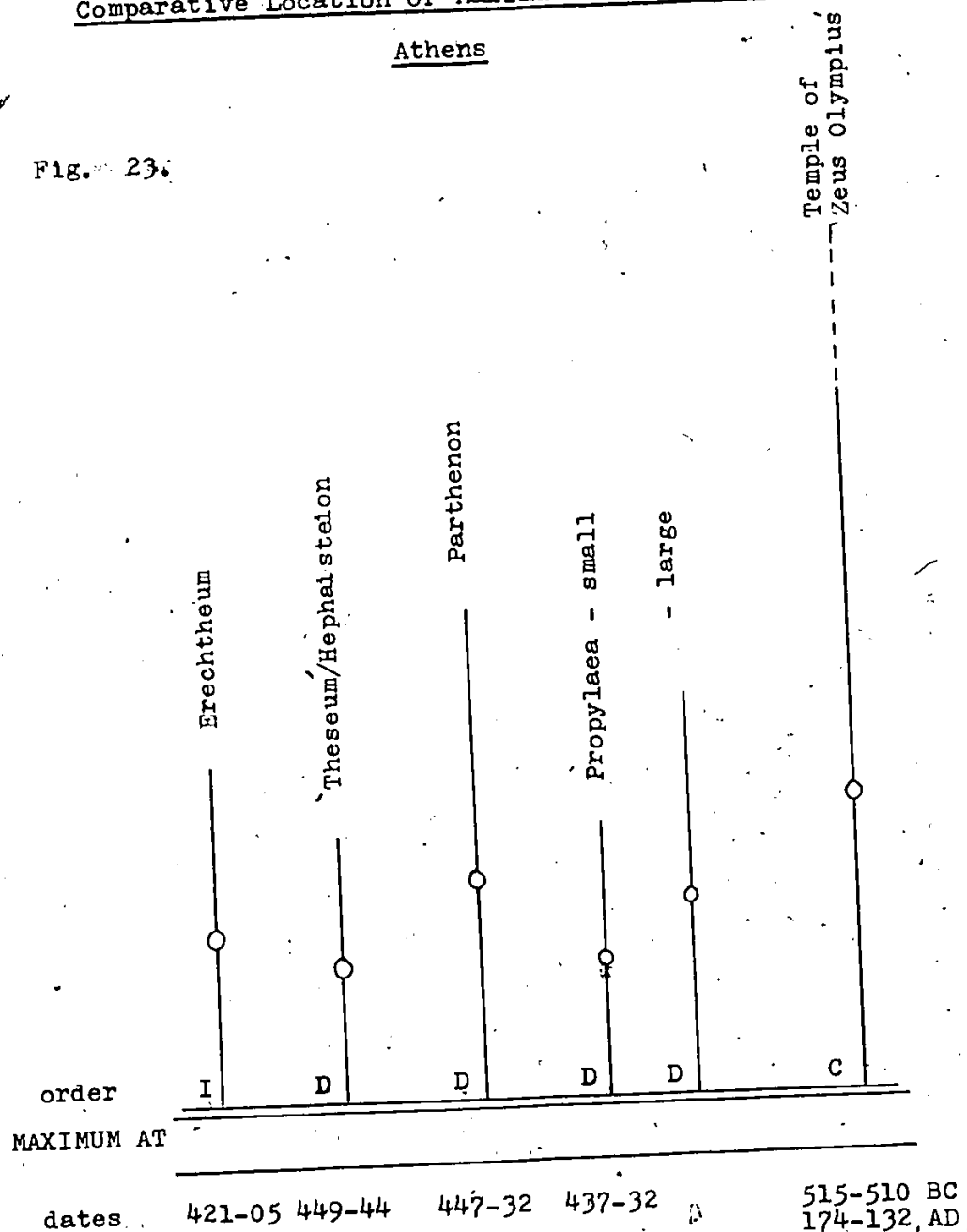
It will be noted that the first and last columns in the chart on page 64 are not Doric. The Erechtheum is Ionic and the Temple of Zeus Olympius (Jupiter Olympius to Penrose) is Corinthian. The date of completion of the latter is also many centuries after the others. In any case, there does not appear to be any real pattern. This is particularly obvious in the column showing comparative entasis in a shaft of 31.43 feet (Parthenon measurements). If the numbers in this column appear to grow in terms of size and/or units, let us remember that the temple columns are not arranged in chronological order, nor in order of height of shaft, maximum entasis, position of entasis, relation to height (page 66), or entasis in terms of shaft length, lower diameter or semi-diminution. They are, in fact, listed alphabetically (if one substitutes the word Hephaesteum for Theseum). One should also note that only in the case of the maximum entasis of the large column in the Propylaea is the measure a 'standard unit' (.0627 or one dactyl or 1/16 of a foot).

There are several ramifications of the above information. Vitruvian formulae do not hold. The Greeks apparently did not use mathematics or a standard never-changing system in arriving at entasis; if they did the 'system' does not show in the permutations and combinations suggested by the headings on our chart. If the Greeks did have a system it has escaped detection.

Comparative Location of Maximum Entasis in Periclean

Athens

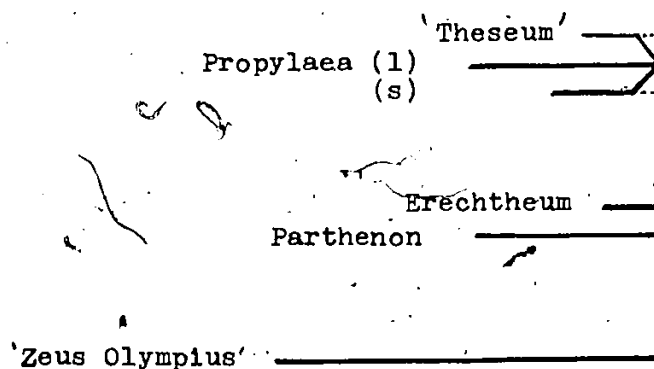
Fig. 23.



¹All information is adapted from Penrose. The Temple of 'Zeus Olympius' is included for comparison sake.

Comparative entasis in a shaft of 31.43 feet
 Entasis is actual graphic size; location is
 plotted to scale at proper height above the
 stylobate.

Fig. 24.



No intelligent relationship suggests itself to the author between the varying degrees of entasis and the height above stylobate. The fact that the Theseum is closer to sea-level than the others suggests no pattern either. Probably the entasis was arrived at by an 'ad hoc' or fairly elastic formula.

7. Standard Ways of Illustrating the Entasis Method

Vitruvius, the first even to mention entasis, referred to a diagram which is missing. Centuries after the fact his De Architectura was 'printed' and in the edition of 1511, one Fra Giocondo provided his own somewhat cryptic illustration to replace the missing original, (below right).¹ The book instigated a new approach to architecture in Italy. Building became a theoretical as well as a practical science. The real significance of the word 'Order' was better appreciated and artist-architects set about to discover the 'rules' of the ancients. They had oral traditions, customs handed down through the old guilds, their new-found Vitruvian rules and their own ingenuity to guide them. Their keen humanism would once again make man the measure of columns and other architectural elements. Unfortunately, they were to rely more on their sketching ability than on words - rather

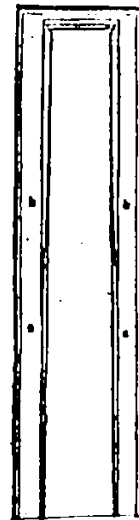


Fig.25. (from Morgan's
Vitruvius, p. 87)

¹The identifying letters perhaps suggest a sequence, i.e. from (a) at center, up the column shaft to (b) and then back down to (c).

like any initiated person - to convey their message.¹ The 'reader' is left to himself to cope with the geometry, mechanics and sequence of operations involved. This is fitting, for it was probably this way in ancient Greece where the architect communicated details of the design to the builders by means of an *'αναγραφεύς'*.²

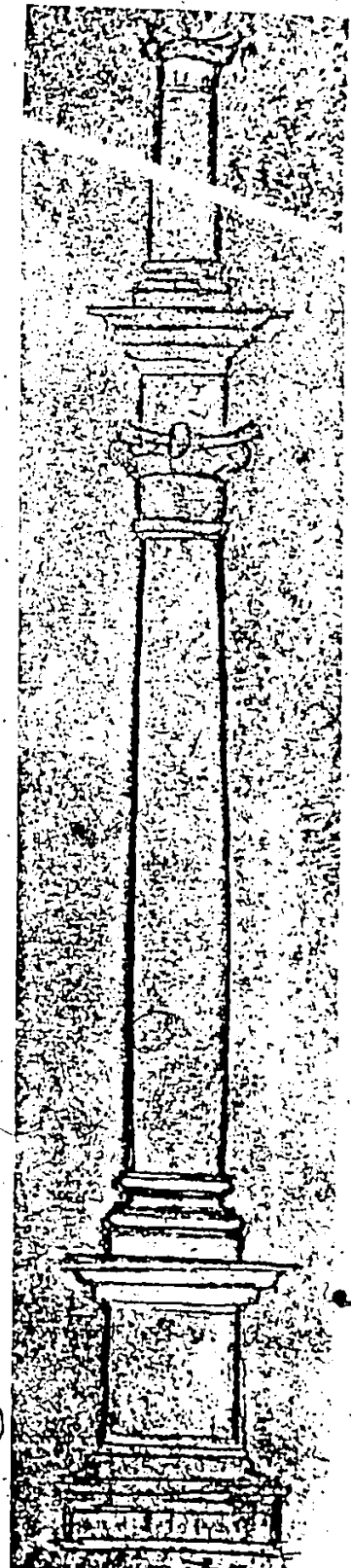
The pages that follow will illustrate the various generally accepted techniques for diminishing a shaft with a curved line. Note that simple measurements, Euclidian geometry and unsophisticated tools would be used in these 'hands-on' techniques, and that almost anyone could be taught the method desired.³

Fig.25. (from
Leonardo da Vinci,
p.256)

¹Presumably, even Vitruvius preferred the picture to words.

²Coulton notes that the word can mean drawing, written specifications, or template. He opts for the latter meaning, but in doing so he suggests that the template was the next step in the transition from specimen or *παράδειγμα* ("The Meaning of *'Αναγραφεύς'*"; *AJA* 80, 1976) p.302.

³Leonardo, who was to die just eight years after the publication of *De Architectura*, was one of several artists who noticed entasis but showed no concern in calculating new (?) ways of achieving it.



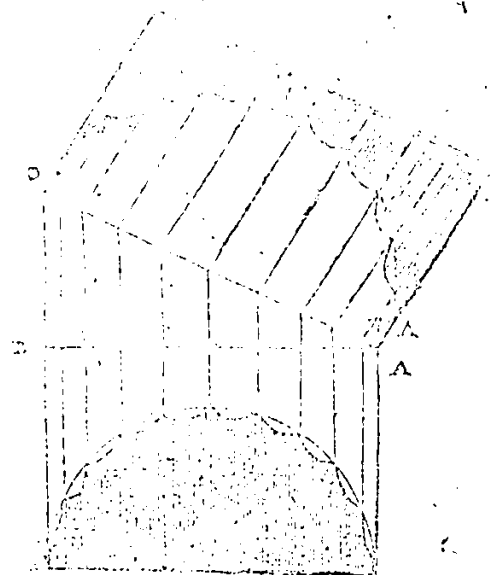
Column - Windsor, Royal Collection,
no. 12608

In virtually all the methods of arriving at entasis there seems to be a relationship between the shaft height, the base diameter and the semi-diminution. It is difficult to say exactly what the relationship is, but entasis is invariably arrived at by manipulating these three dimensions. It might well be that there were various systems for various times and occasions: Asher Benjamin says "experience has taught me that no determinate rule for columns, in all situations, will answer; they must be proportioned according to the weight, or apparent weight that they sustain".¹ These proportions would, however manipulated, produce varying entasis curves, as the following pages will illustrate. The following diagram is reproduced to illustrate one less-than-obvious way in which to arrive at semi-diminution.²

Fig. 27

(Reproduced from Serlio,
Bk I, p.8)

A 2:1 sided triangle is
used to produce taper
and fluting representation.



¹Benjamin, Asher, "Preface to Third Edition", 1814,
The American Builder's Companion, 6th ed., 1827, reprint,
Dover, New York, 1969, p.4.

²Serlio, Libro Primo, p.8.

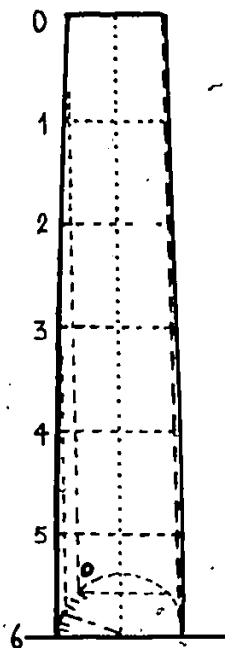


Fig. 28

Method 1 - The 'Old' Method as outlined by Dombart

Verticals are dropped from the edge of the upper diameter to intersect the base diameter at 0. (As in all cases, details are shown for one side only.)

The shaft is divided horizontally into as many equal parts as is convenient. The arc 6 - 0 is divided into the same number of parts.

Verticals are projected from each of the divisions on the arc, so that the first on the outside meets the horizontal 5, the next one meets the horizontal 4, and so on.

A curve is drawn through all these points to produce the contour of the column.

Dombart credits Vignola with 'using' this method.¹ But Nicholson simply calls it 'the old method'.² The Greeks may indeed have used it, but the argument against their doing so is that Nicomedes 'invented' this 'curve' and he lived after the Golden Age. The technique is simple; the argument is weak.

¹Dombart, RE, col.271.

²Nicholson, P., pp. 180-181.

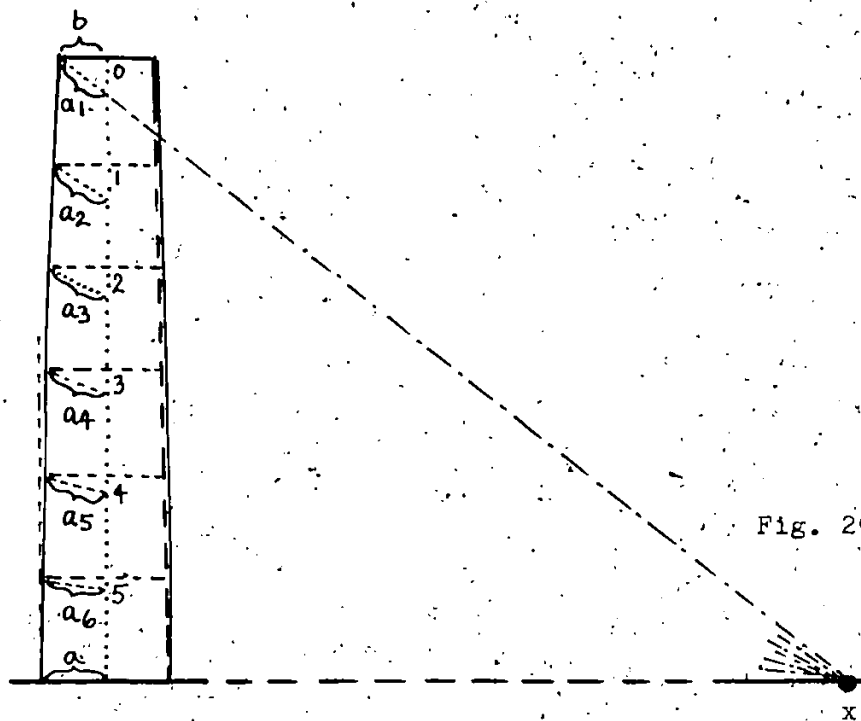


Fig. 29.

Method 2 - as outlined by Dombart

The base line is projected - in this case to the right.

On the outer edge of the top an arc is drawn with the base diameter (a) to cut the axis of the column as shown and produce a1.

a1 is extended to cut the base projection as shown at x.

The shaft is divided into an equal number of parts and horizontals are drawn at each division at 1, 2, 3 etc.

From the point x lines are drawn so that the distance from the center axis to the horizontal is always equal to a or the base radius; a1, a2, a3, etc. are so produced.

The points on the horizontals are joined to produce the curve.

Dombart credits Serlio with the invention of this system¹ but Nicholson credits Nichomedes with the invention of the conchoid and system and mentions improvements in it by Vignola.

¹Dombart, col. 272.

²Nicholson, p. 180.

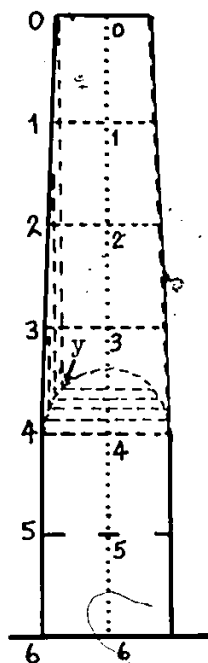


Fig. 30

Method 3 - as outlined by Dombart

The shaft is divided into an equal number of parts and horizontals are drawn at 5, 4, 3, etc.

In this Renaissance method (perhaps inspired by the Silver Age treatment of column fluting) the lower third of the column is left flat, cylindrical and untapered (from horizontal 6 to 4).

On horizontal 4 a semi-circumference is drawn as in Method 1. And as in Method 1 a vertical is dropped from the outer edge of the top diameter to meet this base circumference at y.

The distance from the horizontal 4 (in this case) to the point y is now divided into 4 (the number of parts above the horizontal), and as in Method 1, verticals are projected from these points to meet the horizontals 3, 2, 1. These points, when joined, make up the curve which if projected would be an elongated semi-ellipsis.¹

Nicholson shows a modification of this method in that he does all his figuring from the base line so that no part of the contour is flat. He credits himself with 'inventing' the system. Dombart credits Serlio, and quite rightly so (see next page).

¹Nicholson, p.180.

²Dombart, col.272.

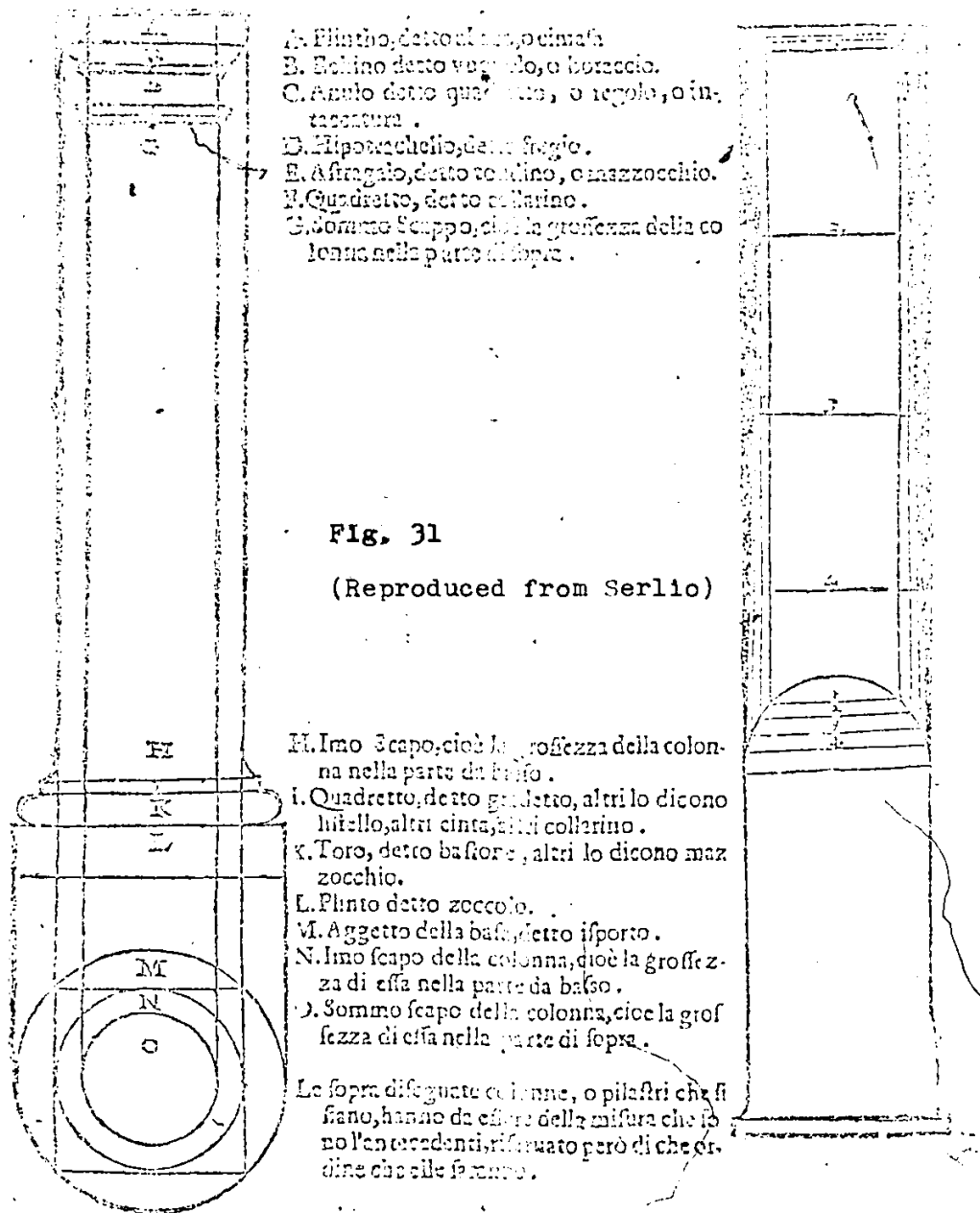


Fig. 31

(Reproduced from Serlio)

Page 128 from Serlio's Libro Quarto shows he used Method 3 in Renaissance times. Asher Benjamin who published the first original American architectural work (The Country Builder's Assistant) in Greenfield in 1797 also published the classic work The American Builder's Companion in 1806. He was to use the same technique on Plate VII of the sixth edition in 1827. It is unlikely Nicholson 'invented' the system in England.

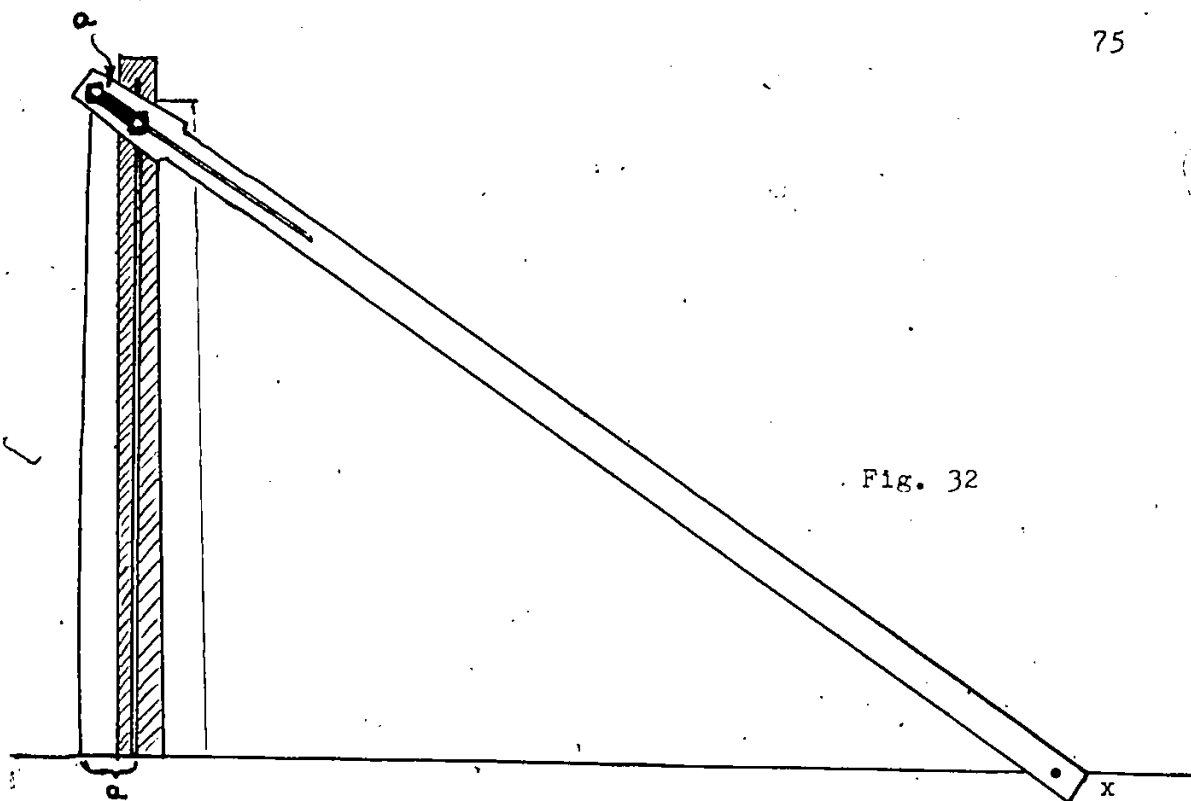


Fig. 32

Method 4 - a mechanical way to draw a Conchoid of Nicomedes

As in Method 2, the base radius is used, in this case in a pole that pivots on point x (arrived at in the same way as in Method 2).

The pole is so grooved that a sliding rule is inset in it. This rule has a nail or metal rod in the right end (in our illustration) and a pencil in the left end.

A slotted or grooved pole is put along the line of the column axis and the nail of the sliding grooved rule is set in the pole's slot or groove so that when the pole is moved the rule's nail moves along the axis.

Since the rule is as long as the base diameter (a) the same conchoid curve will be described in one easy movement by swinging the pole on axis x .

Reverse to do the other side - or use the same template formed by 'boxing' the column.

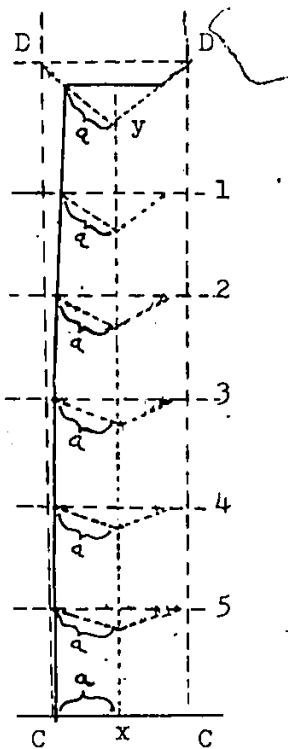


Fig. 33

Method 5 - to draw a conchoid curve in a confined space

The edges of the base are projected straight up on each side from C towards D, a point slightly above the top of the column.

An axis line is projected up from X.

The base radius (a) is transposed from the edge of the top diameter to the axis at Y, as in Method 2. This line is then projected up to meet the base vertical at D.

CD on both sides of the column is divided into an equal number of parts and horizontals are drawn (1, 2, 3 etc).

The partial axis line XY is divided into the same number of equal parts as CD. From these axis divisions with radius (a) arcs are drawn to cut the horizontals (1, 2, 3, etc)

The points where these arcs cut the horizontals, when joined, will produce a conchoid, much as in Methods 2 and 4.

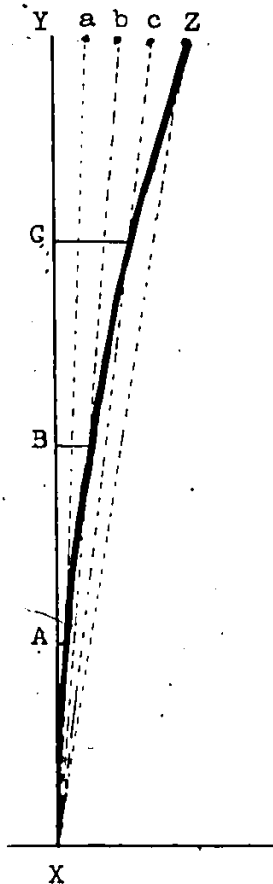


Fig. 34

Method 6

XY, the column height is divided into equal parts (C,B,A).

YZ, the half-diminution or distance from the edge of the base to the edge of the top diameter (measured horizontally), is divided into the same number of equal parts as is XY, at a,b,c.

Working lines are drawn from X to a, b and c.

Horizontal lines are drawn from A, B and C to meet these lines radiating from X. The points formed at Aa, Bb and Cc form the curve of the entasis.¹

¹Nicholson, p. 180. (He claims to have invented this system.) It should be noted however that the technique was already in use in the New World (perhaps as early as Jefferson's time). Asher Benjamin illustrates it on Plate XII of The American Builder's Companion of 1827.

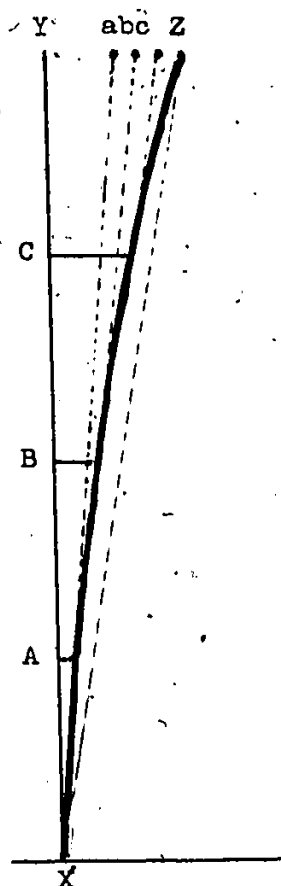


Fig. 35

Method 7 - to produce less entasis than in Method 6

Proceed exactly as in Method 6, except that only the half of the semi-diminution immediately adjacent the column is divided to produce a, b, c.

Note that there are many other possible patterns that would produce different entasis contours, e.g. One might use the half-semi-diminution on the left - or away from the column - or one might use the same units on each side of the center line (Xa in our diagram). One might also use another proportion of the semi-diminution instead of one-half.

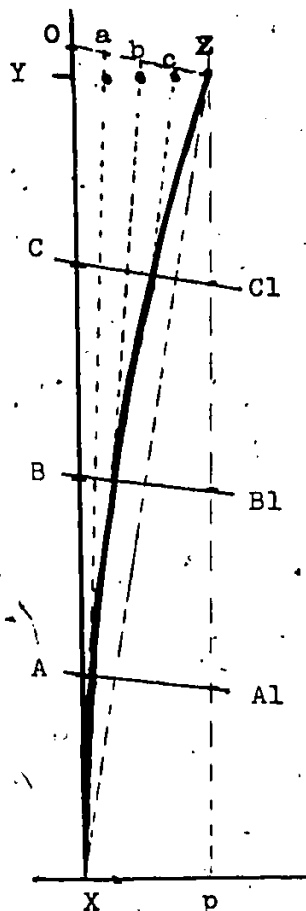


Fig. 36

Method 8 - invented (?) by Nicholson (p.180)

As in Methods 6 and 7, XY is the shaft height and YZ is the half-diminution.

XY is extended a bit above the shaft; a vertical is dropped from Z to (p). At Z a perpendicular OZ is made to XZ so that it cuts the projected XY at O.

This line OZ is divided into an equal number of parts, a, b, c.

XO is divided into the same number of parts at A, B, C.

Zp is divided into the same number of parts at Al, Bl, Cl.

C is joined to Cl, B to Bl, etc. and X is joined to a, b and c.

The points formed by C-Cl on Xc, B-Bl on Xb, etc. form the entasis curve.

Note that many variations are possible here too, e.g. a slightly different contour could be had by subdividing at the dots shown (divisions on the column's top drum) rather than by dividing ZO.

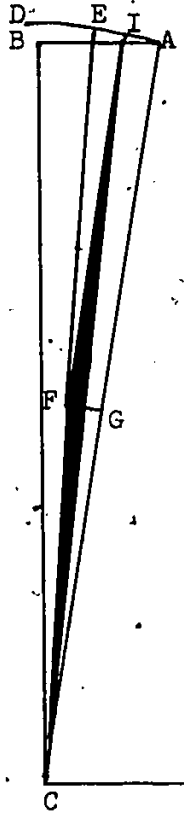


Fig. 37

Method 9 - exactly as described in Nicholson, p. 181.

Join AGC, and bisect it by a perpendicular, FG; on the center, C, with the radius, CA, describe the arc AD; divide AD into two equal parts in E; draw EFC, and parallel to GA draw FI; make an angle, CFI, upon the edge of a board or rule, put in pins at the points C and F, and with a pencil, upon the angular point F, while the rule is moved from F to C, keeping the side FI of it upon the pin at F, and the same side FC, upon the pin at C, the angular point F will describe the contour of the column between F and C. In like manner, by removing the pin out of C, and putting it in A, the part FA may be described.

The same curve might have been found by one continued motion from A to C, as follows: suppose the line DC to have been produced to a point X; the supposed line

CK to have been equal to CD: and an angle, having been made upon the edge of a thin board, equal to ACK: then the contour AFC would have been described in the same manner, between the points A and C, as each of the former parts shown by the figure. It is obvious, that by this last method, it would be requisite to have the machine twice the length of that in the first method; from which it would become more unmanageable in the formation of the curve, and inconvenient in many situations, for want of space to extend it to the necessary distance.¹

This description is given in Nicholson's words because it was felt that his voice should be heard, since he is the only one to spell out in words what his diagrams were meant to say. More important, however, is the fact that the emphasized words in this method suggest the simple devices that might well have been used by the ancient Greeks, viz. thin board, rule, pins, pencils, etc.

It is also worth noting that Nicholson's illustration for what is called the 'Old Method' - our first - differs from the one illustrating the Dombart article in RE in that there is a dark area down the right side of the column. He calls it the 'diminishing rule' and he draws attention to the fact that the curved edge is concave - the reverse of the convex contour of the column. Such a curved diminishing rule could be made by a number of mathematical - or non-mathematical - ways. Might not the Greeks have used such a template?

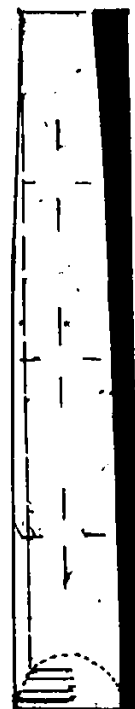


Fig. 38

¹Nicholson, p.181. (my emphasis)

8. Factors affecting entasis curve

One must concede that in canonic times the swelling was generally dependent on the absolute measurements of the column and that height of shaft played an important role. (We know that there is no entasis in 'small' shafts, as in the Temple of the Wingless Victory.)¹ If 'total dimensions' did not expand, but only the height of a shaft, then we can expect the curve - whatever its actual distance above the line of taper (e.g. see page 64) - to be rather flat.

It might well be that entasis was related to other columnar dimensions. The diagram at right (from Serlio's Libro Quatro, p.143) suggests that entasis might be determined in terms of the width of the fluting, or even the diagonal of the fluting squared. This type of approach is entirely in keeping with the Serlio diagram reproduced at the beginning of this section, and with the recently advanced theory of Richard Tobin on the Canon of Polycleitos.²

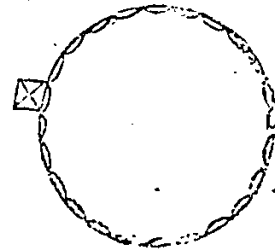


Fig. 39

¹Dombart, col. 274. (He also refers to the entasis free 2.5 m high columns of the old Tholos at Delphi and to the Temple of Phigalea.)

²Tobin, Richard, "The Canon of Polycleitos", AJA 79, 1975, pp. 307-310.

There are two other hypothetical considerations, for which there appears to be no obvious clear-cut answer. What was the relationship of entasis to the actual site of the building. Dombart says that "entasis had to be stronger the more the building appeared to be seen from a deeper point of view, as for the Propylaea at Athens."¹ There is no suggestion in any of the books consulted as to what effect site elevation would have on a) the degree of entasis or b) the location of maximum entasis. A perusal of the comparative entasis chart on page 66 will show that there was no obvious relationship in the buildings measured by Penrose. Closely related to this problem is the one of scale of the column in relation to the viewer. The diagram on the next page is from Serlio's Libro Primo, page 9. It illustrates quite simply that if a pillar (in this case) is to appear to be made up of equal units, the units at the top must be progressively taller than the ones at eye level. Was this a factor in the degree and position of entasis? It seems likely that it was, for there are several references to the moon illusion (same principle at work) in antiquity, and we know that the Greeks made use of this visual control technique at Priene.

¹Dombart, col. 274.

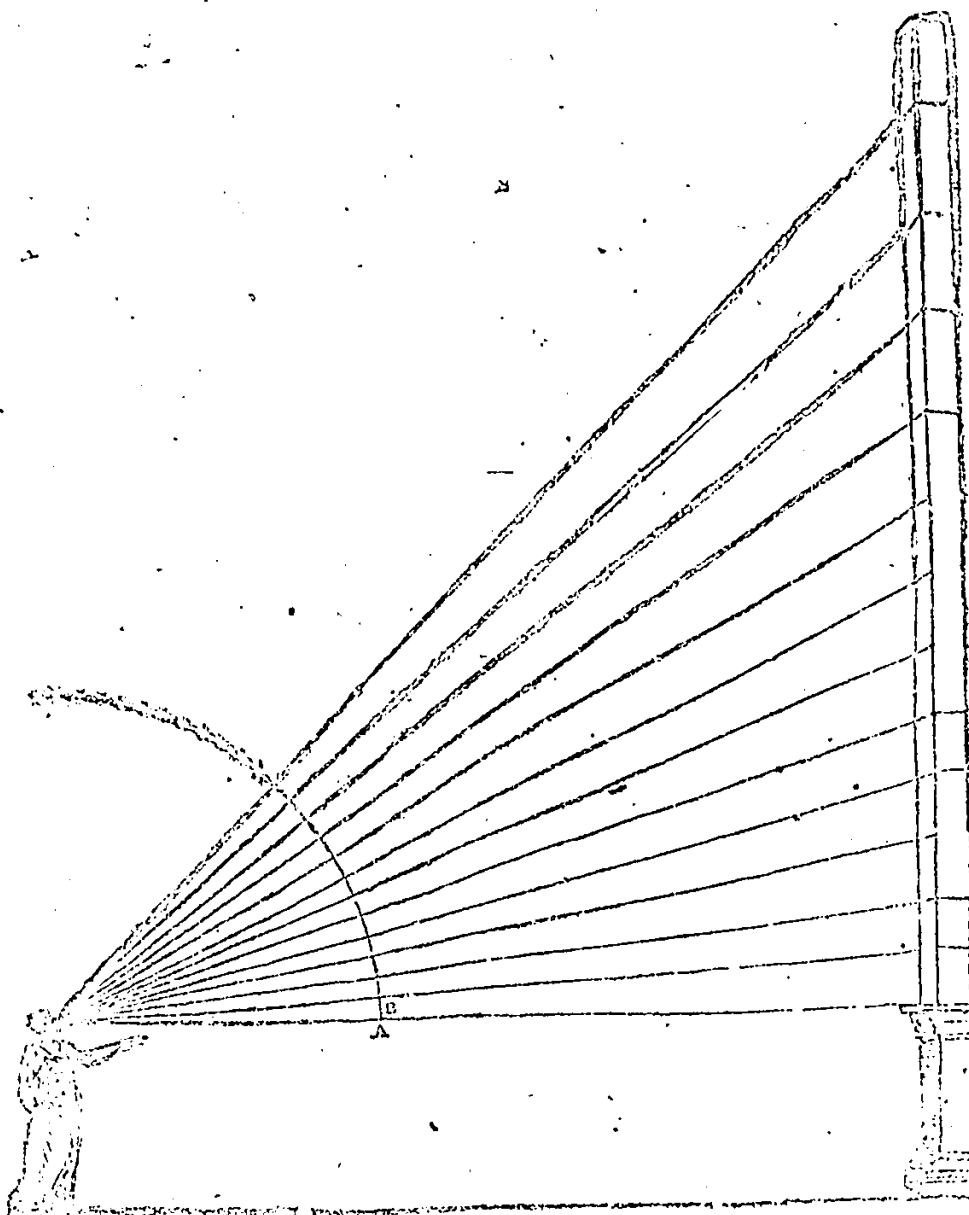


Fig. 40

(From Sebastiano Serlio)

Presumably there was an inscription on a temple at Priene in which the letters were arranged vertically and in order to make them appear the same size they were actually increased in size toward the top according to the principle illustrated in this diagram:¹

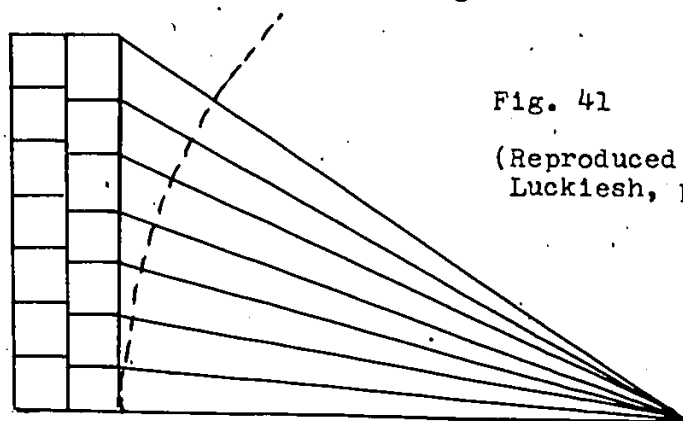


Fig. 41

(Reproduced from
Luckiesh, p. 199)

¹Luckiesh, p. 199. Choisy (p.319) also says: "Un texte de Platon, dans le dialogue du sophiste, établit que l'usage était d'exagérer la hauteur des parties qui devaient être vues d'en bas et réduites par la perspective." Vitruvius reduces the principle to a rule and formula in tilting elements, the degree of tilt being in direct relation to their height. The author has made an all-too-brief study of the inscription at Wroxeter City (Uriconium) which is noted for its excellence. Rough measurements indicate that the same principle was used: the bottom line is a given number of units, and each successive line above it is two units higher - with the exception of the top line which increases by four units (probably out of deference to the Emperor Hadrian's name). The importance of this fact is the suggestion that compensations were made for height and/or perspective diminution by the ancient Greeks and Romans and may also have been factors in establishing entasis curves. One might even suppose that the various formulae for arriving at entasis might be varied by using polygonal increases instead of equal divisions in dividing the shaft height or semi-diminution.

9. Executing the Curve on the Column

Penrose, who produced the elaborate formula (page 99) for arriving at entasis, also made use of logarithmic tables to arrive at hyperbolic coordinates to compare with his measurements.¹ Elsewhere, he adds "But we can hardly suppose that the geometers of Pericles' time could have solved such a problem; and it seems more likely that the particular curves were found by a diligent selection from a number of careful geometrical drawings of different examples."² We have already seen that Stevens reduced conic curves to a small diagram which could have been used to convey all the necessary information to the masons. 'Scamilli impares' might have been used to convey entasis as easily as they conveyed horizontal curvature (Figure 79). There is some suggestion of this 'prior knowledge' in the fact that column drums have been found rough dressed to a taper.³ If the mason could tailor his stone to accommodate the coordinates at each end of the drum, he would in fact have accommodated all the coordinates in between, because a) the drum side might be flat (as in the Parthenon), b) the entasis curve would be proportionally minimal in such a short distance,

¹Penrose, p.4

²_____, p.121

³I am indebted to Professor Hodge who advises me that at Cave di Cusa the drums are already tapered while attached to the living rock in the quarry.

c) the thickness of the rough dressing would, in effect, accommodate the entasis, however extreme it was. But we can still only guess how entasis was actually applied.

Measurements could certainly have been painted or incised on drum heads, but these would have been lost inside the column when the drum was put in position. No work has been published, to my knowledge, on the nature of anathyrosis within a given column. Did measurements stay the same, or do they reflect the taper and perhaps the entasis? We can say for sure that when the column was first erected, the fluting at top and bottom was already started, but the stones in between had yet to be given fluting, entasis and a finish. How did the Greeks proceed?

Penrose believes that a full-sized mould or template was absolutely necessary.¹ He offers the following diagram (Figure 42)² to support his case. It will be readily noticed that someone has already determined the exact nature of the curve and drawn it on a template. The template is brought into position against the comparatively rough surface of the column, and the top and bottom are anchored to the finished portions already mentioned. A drill is then used to "point off" the work

¹Penrose, p.121

²_____, Appendix, Pl.47, fig.6.

by sinking holes of equal depths either from fixed points upon RR' or points selected upon the columns themselves. The template would be moved around the column and all the points would mark the outer edge of the fluting - the entasis. The fluting itself would be arrived at with more manageable templates.

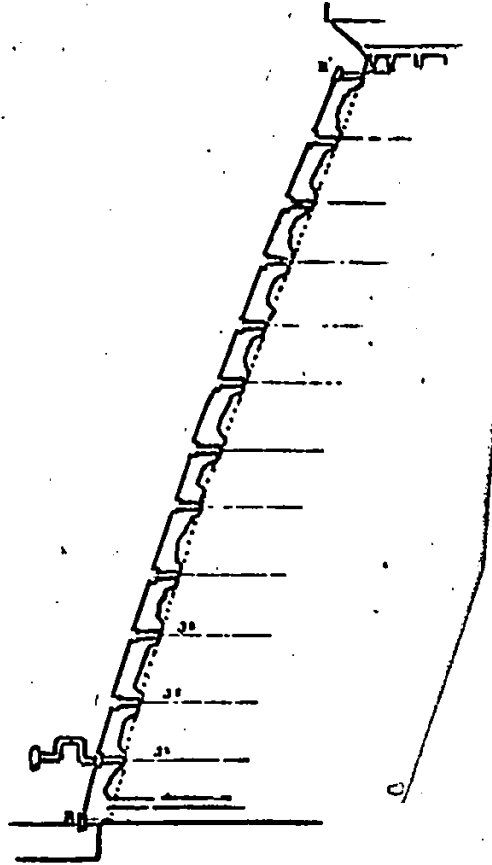
One would have to consider several factors and compensate accordingly. Drills do get dull, and in the process shorter, so that the points they gave would be increasingly untrue. Some compensation would have to be made for the tendency of the material to dun or 'bruise'. Finally, early and later columns often had a coating of stucco. Can we assume that the above process would work as well, or at all, on a stucco surface? Or was there still another way?

A comment by R.M. Cook with reference to the reproduction of statues is perhaps germane:

It was not until the last century B.C. that there are traces of any system of pointing. . . the method by which positions determined on the model are transferred precisely to the block from which the final statue is to be carved, - and even then the points were far enough apart for large areas to be left to freehand carving.¹

¹Cook, R.M., Greek Art, Its Development, Character and Influence, Farrar, Straus, Giroux, New York, 1972, p.76.

Fig. 42
Penrose's template



Nevertheless, Penrose's template would have worked equally well on the Parthenon entasis (where only the drum top and bottom edges were on the curve coordinates) and on the Erechtheum (where the curve was continuously applied). A perusal of the figures he provides¹ will show that the offsets to the column's edge are in every case greater

¹Penrose, p.41.

than the offsets to the hyperbola. The significance is not in the fact that there are errors between the offsets (.0011 at the greatest) but that all errors are in the same direction and can be explained by the fact that as the holes were made down the shaft, the drill got progressively duller. It might also have been that one end of the template was not properly adjusted, or that another, or an auxiliary, method was used to prevent undulations. (The marvel is that the greatest error is one thousandth part of a foot - an admirable degree of 'tolerance'.)

Stevens also rules out complicated methods of laying out the entasis.¹ He further states that he knows of no Roman column without it.² This must surely imply that the application of entasis was a relatively easy thing to do. Stevens also feels that wooden templates would do for small columns, but would be impractical for large shafts. He suggests a taut wire stretched along the arris might have been used for 'pointing'.³ He rules out - as do others - the use of lathes and he mentions the method used by his contemporaries in Italy: "The Italian architects of today take a long wooden straight edge, bend it to the desired entasis, and then draw the curve".⁴

¹Stevens, p.148.

²_____, p.121.

³_____, p.124.

⁴_____, p.126.

10. Local Examples of Entasis

It is a paradox that entasis was being used in North America at the precise moment it was 'discovered' on the Acropolis.¹ Since Roman and later architects had not used 'canonic' Greek entasis, it follows that we cannot expect Hellenic purity in the works we find in New England, Ottawa, or even the Upper Ottawa Valley hamlets.² Still, the fact that the tradition lasted until just a few decades ago in places like Renfrew, Ontario, (population 9,000) suggests that entasis had a practical or vital role to play. It should be noted that a swelling is imparted to very small columns that hold up porch roofs on domestic dwellings, and to columns in pseudo-Gothic churches.³ It is not to be found on very, very squat elements barely three feet high. The Greek principle was at work, though under less sophisticated circumstances.

It should also be noted that most architects who graduated in the last three decades from English as well as Canadian schools did not study the nature of entasis, or how to impart it, and that locally, carpenters turned out porch columns on a lathe. Most significant, perhaps is the

¹Thomas Jefferson is credited with starting the Classic Greek Revival in America: cf. Talbot Hamlin, "The Greek Revival in America and Some of its Critics", The Art Bulletin, Sept. 1942, p.248.

²We have Asher Benjamin's word that "Experience has taught...that no determinate rule for columns, in all situations, will answer", Benjamin, p.4. I suspect that an ancient Greek would find his attitude commendable.

³The principle that entasis was vital seems to override the optical or illusory considerations.

fact that architects in the New World - and handymen - had available books that did show clearly how to arrive at entasis. They also used trammels to execute sophisticated curves mechanically, and when imparting entasis according to Methods 3 and 6, they found the points, and in those points tacked brads or nails and bent a lath or thin strip of wood along them so that the curve could be easily marked out.¹

Students of Classical Archaeology at Renfrew Collegiate used these techniques to impart entasis to columns for stage sets. They found that a variety of curves could be imparted using the same method if the lath used was made to taper so that its resiliency was altered. (This presupposes a minimum number of vertical divisions in the formulae.) Was this also a factor in the varied curve in Greek antiquity?

¹Benjamin, pp.17, 38. He also advises the worker to use the same procedure for any of the orders he works with.



Fig. 43 Entasis in the north Eastern United States.

The Neo-Classical influence was to move north of the border and have an effect on church, public and even private architecture in Canada. Pictures above are the three orders as seen on Watertown, New York's Clinton Street between Sherman and Holcomb. The Doric (Masonic Temple), the Ionic (Library) and the Corinthian (People's Bank) show obvious entasis which is easily seen by comparing the curve with the nearest perpendicular element. A Jefferson County Historical Society brochure mentions that modifications were often made to 'pillars' (columns are illustrated, though) so that they could be constructed locally to effect a saving. (photos by the author).



Fig. 44

Entasis in Renfrew Ontario: The Doric column was made by a Mr. Castonguay of Otter Lake, Pontiac County, Quebec, for the M.J. O'Brien home. The Barr Street porch is shown. Mr. Castonguay's grandson remembers his grandfather using a lathe, but he can't say for sure if a template was used for measuring. The Ionic column from the Prince residence on Lochiel Street was fashioned fifty years ago of wood.

Entasis is quite obvious in Valley churches, e.g. Arnprior's St. John Roman Catholic Church. To detect it, the viewer has but to position himself/herself so that a perpendicular is aligned as closely as possible with the edge of the column. Doorways and wall edges (however untrue) serve quite well to point out the existence of curvature.

ENTASIS - THE 'WHY'

1. Entasis and Illusion

There can be little doubt that the ancients concerned themselves with illusions in architecture. Vitruvius, who had better access to both sources and tradition than we do, accepted the sole purpose of entasis to be to correct optical illusion.¹ Penrose, considerably later, conducted his survey "chiefly with reference to optical refinements" of the Athenian buildings², and Luckiesh, an expert in the field of illusions, made several references to the Greek skill in constructing buildings to counter-act visual illusions.³

Vitruvius traced the writing of treatises having to do with architecture to Agatharcus' comments on his famous theatrical scene - itself an exercise in creating a three-dimensional illusion on a two-dimensional surface. Democritus and Anaxagorus wrote on this same subject showing how by "deception a faithful representation of the buildings might be arrived at".⁴ Indeed, the Greeks published

¹Vitruvius, III, 13; Robertson, GRA, p.117; Plommer, Hugh, Ancient and Classical Architecture, Simpson's History of Architectural Development, Vol.1, Longmans, Green, London, 1956. p.140.

²Penrose, title page.

³Luckiesh, M., Visual Illusions, Their Causes, Characteristics and Applications, Dover, 1965, pp.7, 195.

⁴Vitruvius, VII, 11, 12, (my emphasis).

'many books in this field' (architecture)¹ and Vitruvius acknowledges that he "gathered what...was useful"² in forming his own work. He makes specific mention of the joint publication on the Parthenon by Ictinus and Carpion.³ This latter treatise became the model and stimulus for later comments on architectural techniques by the architects themselves.⁴ We have none of the 'many books' by the Greeks. We can safely surmise that, since Vitruvius made much of the optical effects of architecture, so must the Greeks have done before him. "The architecture of classic Greece displays a highly developed knowledge of many geometrical illusions and the architects of those far-off centuries carefully worked out details for counteracting them."⁵ This should not be too surprising if we accept Luckiesh's further statement that "no view of a group of buildings or of the components of a single structure can be free from optical illusions".⁶ The Greeks had a passion for three-dimensional form whether it was sculptural or architectural. They merely accepted the challenge!

¹Vitruvius, VII, 14.

²_____, VII, 14.

³_____, VII, 12

⁴Wycherley, Richard Ernest, "Ictinus", OCD, 2nd ed., 1973, p.540.

⁵Luckiesh, p.195.

⁶Luckiesh, p.195.

Since we have no published works by the Greeks on how they countered the vagaries of vision we must work from what we know and from the 'delicate deviations' they made from the norm in building. At best, we can speculate and theorize as to their methods and intent.

Entasis, wisely and/or tastefully used, offsets both attenuation and concavity in a straight-sided shaft. It should be noted that several factors are at play and that illusions are said not to occur in shafts that do not diminish in size or in those which are attached to walls. In Periclean Athens entasis was not used in antae and walls.¹ In Roman times the curve was imparted with more 'gusto' - but considerably less taste - to other architectural elements, eg. the pilasters at Baalbeck.

The tapered column without entasis would appear concave just below center. This perhaps occurs because of the height of the column above the viewer. Perhaps it is related to the intensity of the Greek light during working hours. From the point of view of aesthetics we can say with certainty that the lower parts are heavier masses while the upper parts are lighter and, because of the more obvious taper these upper parts thrust upward more. The lower half of the column would weigh more, in actual fact and

¹Dinsmoor, AAG, p.169.

to the eye. As we shall see later, there is also the possibility that tilting the head upward has an effect on the viewer's perception which contributes to the impression of concavity. Finally, there is the possibility that the phenomenon of the eye always seeking an 'optical center' above the mathematical center is somehow involved.¹

Damien of Larissa apparently wrote on how a cylinder can be strangled by its milieu.² Vitruvius, as we already noted, believed entasis' sole purpose was to offset this visual effect of concavity. He also tells us that the proportions of the Doric are taken from man's.³ Perhaps this has something to do with the oft cited claim that the column is like a flexed muscle.⁴ In any case, the addition of more material at the point of greatest tension would impart actual strength to the column, while at the same time correcting the disagreeable illusion. One must doubt, though, whether the Greeks, who apparently did not use rectangular beams to make full use of their greatest stress capabilities, were indeed capable of measuring the stress of a column and actually

¹This phenomenon is exploited by those who frame pictures so that the lower border is deeper than the others.

²Choisy, A., Histoire de l'Architecture, p.321.

³It is easier to see a related bulge at hip-level in the 'feminine' Ionic than in the Doric which appears to bear no resemblance to the ideal kouros.

⁴Perhaps the more slender Ionic with its 'feminine' measurements came first and prompted the Dorians to see more masculine proportions in their more squat column.

compensating for it.¹ It remained for Penrose to produce a (rather unwieldy) formula for entasis:

Let e represent the linear amount of the maximum entasis, θ the angle included between the bounding lines of the column, h the length of the shaft, d the semi-diminution, and let 5.5 feet be assumed as the height of the eye:

The following equation will embody all the prescribed conditions

$$e = m \left(\frac{(h - 5.5 \text{ feet})}{h} \right) d \times (1 - \sin \theta)^n$$

And the constants m and n must be determined from the measurements of actual entasis.²

Penrose goes on to apply and very nearly arrive at the Erechtheum entasis. He misses the Theseum (Hephaestæion) by one-third underestimation. Then he confesses that "I am far from supposing that the Greek architects made use of any rules so complex."³ (and possible, we might add, only with logarithmic tables.) And he cites Philo, an author of about 200 B.C. (quoted in Schneider's Vitruvius, Tom. II, p. 426-427):

ΤΙΝΑ γὰρ τῶν κατὰ μέρος ἐν αὐτοῖς
ὑπαρχόντων ἰσοπαχῇ τε ὄντα καὶ ὀρθά,
ἐδοκεῖ μήτε ἰσοπαχῇ μήτε ὀρθὰ εἶναι διὰ
τὸ ψεύδεσθαι τὴν ὅψιν ἐπὶ τῶν τοιούτων,
μὴ τὸ ἴσον ἔχουσιν ἀπόστημα. διὰ τὸ

¹Hodge, A.T., The Woodworks of Greek Roofs, Cambridge, 1960, p. 92.

²Penrose, p. 124.

³_____, p. 124.

τῆς πείρας οὖν προστίθεντες τοῖς
 ὄγκοις καὶ ἀφαιρῶντες καὶ μύουρα
 ποιοῦντες καὶ πάντι τρόπῳ πειράζοντες
 κατέστησαν ὁμόλογα τῇ ὁράσει καὶ
 εὐρυθμα φαινόμενα.

For some things, although with reference to themselves they are both parallel and straight, seem not to be parallel and straight; on account of the deception of the eye respecting such things, as it views them from unequal distances.

Therefore by the method of trial, by adding to the substance and reducing it, by curtailings, and by experiments in every possible way, they (the ancients) made them regular to the eye, and to the appearance of good symmetry.¹

Greek mensuration was staggeringly poor and unwieldy.²

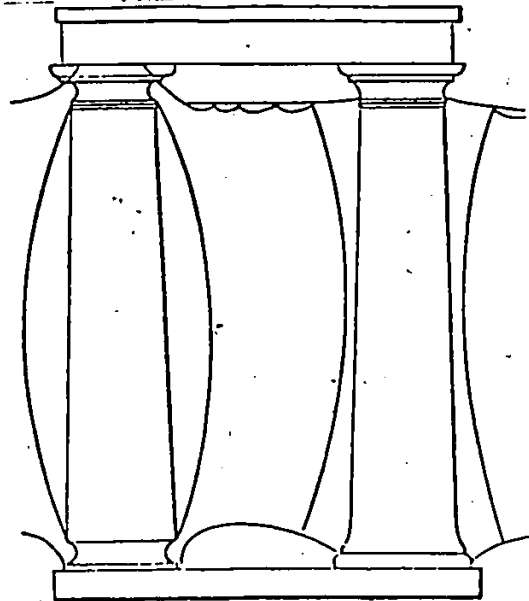
It would seem that the 'eyes' have it, that the use of entasis was to counter illusions that displeased. This suggests that the role was not only optical but aesthetic and subjective. But then, are these not interrelated?

¹Penrose, p.124, (my emphasis).

²Durant, Will, The Life of Greece, Vol II of The Story of Civilization, Simon and Schuster, 1939, pp.337-8.

Deflection

Penrose uses the following figure (Figure 45) to show the effect of deflection which is produced by contrasting lines. The columns are drawn with straight tapering lines for sides. The one column appears to have entasis; the other appears to be attenuated by the contrasting lines



(from Penrose,
p.104.)

Fig. 45 Deflection showing convexity and concavity

close to it. The illusion is real enough, but one should observe that it is made all the more convincing by the exclusion of an abacus and the inclusion of corroborative details that do not exist in a Doric shaft's base. One wonders where one would encounter such acutely contrasting lines in the average Greek temple, except in the play of shadows that fall diagonally along the flank or façades. These would occur largely at the corners and affect the

corner column more than others. (Luckiesh gives examples of deflection in columns but he uses Roman, Gothic or flattened arches behind them to achieve the effect; he does not use a Greek example.)¹ Goodyear comments on Hauck's 'theory of the echo' in spacial contraction of columns at the angle.² Perhaps giving entasis to the end columns did set up a chain reaction that resulted in entasis to each column. It is a pity that statistics do not exist for all columns along a flank or facade to indicate whether such compensation was made.

Irradiation

Penrose also suggests that 'chiaro-oscuro' inequalities in the column itself and in the background make the use of entasis necessary.³ Luckiesh devotes a full chapter to 'irradiation and brightness contrast'.⁴ Figure 26 shows three columns A, B, C. A has entasis; B and C do not. The darkness should press in on B and make the middle concave to the eye. Likewise in C, the eye is drawn to the top and bottom and so the middle, getting little attention, will appear concave even though it is

¹Luckiesh, p.102.

²Goodyear, W.H., Greek Refinements, Yale, 1912, pp.139-40.

³Penrose, p.107.

⁴Luckiesh, pp.114-123.

against a light background (as a corner column might be). Column A, be it against a light or shaded area, has entasis which defeats the tendency to see concavity, whether caused by attenuation, deflection or irradiation:

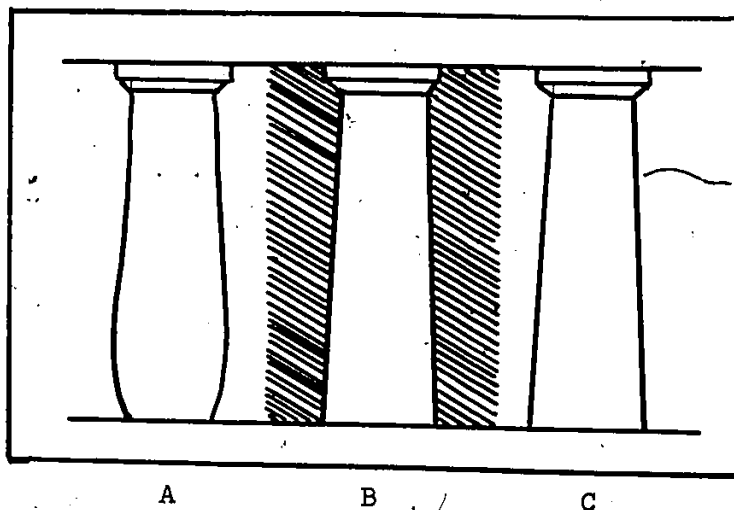


Fig. 46.

Similarly, in Figure 47 there is a single straight-sided tapering column against a partially shadowed background. The top is against the darkest shadow and the light column is reinforced, as it were, and seems larger. (The expanding capital and abacus, which form the transitional elements as our line of sight passes from the vertical to the horizontal, assist in this illusion.) Similarly, the bottom melts into the bright background and seems larger because its sides seem less obvious. The middle part is against a mid-tone and does not seem to get larger, ergo it looks smaller and concave. Entasis, tastefully imposed, would correct this.

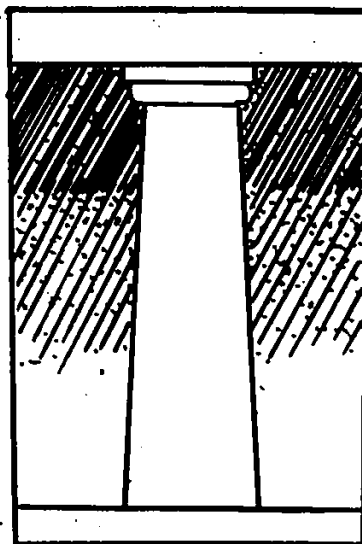


Fig. 47

In this respect it is interesting that Penrose measured a second Parthenon column, the third from the N.E. angle of the temple on the north flank. He gives four tables of measurements¹ and concludes that the curvature of entasis is more accurate on the outside of the column than on the inside (which was never visited by sunlight). He also observes that the outside edge is more accurately carved than the inside edge of the fluting. Both observations suggest that the role of light on the general effect of the building and more particularly on the column itself was a serious consideration of the Greek architect. We shall not treat fluting in detail, but it is worth noting that a) fluting was apparently designed to play with light and to contribute to the particular effect of the column and the

¹Penrose, pp.121-22.

general effect of the building, b) the entasis curve is carried up the outer and inner edges of the fluting, c) the subtlety of the arc used varied with time and place - and, perhaps, with knowledge of applied conics. In the Parthenon we have fluting that even increases in depth as it reaches the top of the shaft. This obvious attempt to control shadow suggests that the Greeks used fluting in a plastic way - as they used line and shape in applying entasis - to direct one's eye up and down, back and forth, and, probably, in and out over the surface of the building. What effects they consciously hoped to achieve and how they arrived at a formula for doing so, (if indeed they did!), we shall probably never know.¹

¹We see contours when adjacent areas contrast sharply and, surprisingly, certain contours can make large areas appear lighter or darker than they really are. We do not yet understand the neural mechanisms underlying this effect. We do know that artists have used the effects for centuries and that scientific interest started about a century ago when Ernst Mach, Austrian physicist, philosopher and psychologist, discovered the rings named after him and formulated the principle for the effect. When means for direct study of neural mechanisms became available a few decades ago it was ascertained that there are both subjective and objective variables. To further confuse the issue, certain subjective factors can seemingly be photographed! We know that a contour can affect the contrast of the areas it separates; we cannot say for sure why this happens or how elementary processes are organized into complex systems. (Ratliff, Floyd, "Contour and Contrast", Scientific American, June '72, pp.91-101.)

2 . Aesthetics

Aesthetic considerations are akin to the illusory at times; there are unconscious and subjective elements involved which some cannot even begin to make explicit. Yet one should perhaps consider the aesthetic function of a column and show how entasis, employed so that it is not too obvious, enhances the member. Since our concern here will be simply with the direction our eye moves in 'taking in' the column, it is interesting to note that in the Phi-phenomenon study by Max Wertheimer (1912), movement was vividly and definitely observed even when there was no movement, and it was observed by anyone with full knowledge that there was no physical movement. In short, the study of movement in the static is the study of illusion.¹

When we look at a column our eye obviously moves up and down, but the ends assume greater importance, partly because of their situation and partly because of their function in supporting and distributing weight. It follows that the middle does not detain the eye as long, does not rivet attention, and so appears relatively smaller than it is, and so concave.

¹It is a specific study that led to the Gestalt school.

Mavrikios explores this 'plastic balance' between 'borne' and 'bearing' elements and not surprisingly draws an analogy to the way the Greeks imparted a new spirit, hitherto lacking, in their statuary.¹

- 5 In physics weight may have a particular meaning, but this is not true in art. Here it depends each time on how it can be interpreted. The impression of weight is not always in proportion to the mass of the material. A slender body may give a feeling of weight greater than that produced by a thicker body. In addition, the same body may on different occasions give a different feeling of weight from the point of view of 'quality'. The sense of weight which is communicated in these cases depends upon the 'movement' of the body - from the particular articulation, balance and poise of its 'borne' and 'bearing' members. Thus the appearance of weight is determined not only by the quality of the material, but often by the creative spirit alone.²

The best illustration of this last point may seem at first a digression. Michelangelo's first great Pieta is a classic example of genius creating the illusion he desired by playing with 'borne' and 'bearing' members. The pose is utterly impossible. A slight Mary effortlessly holds the inert body of her adult Son on her lap - with one hand - while gesticulating gently with the other. There is no tension, such as we might expect. Michelangelo has used his genius

¹Le Corbusier, the great French modern architect, made the same comparison.

²Mavrikios, A.D., "Aesthetic Analysis Concerning the Curvature in the Parthenon", AJA 69, 1965, p.26.

to achieve that 'plastic balance' between 'borne' and 'bearing'. He did it, in part, by using a format that tapered upward and by imparting columnar qualities to the folds of Mary's robe. The same effect is perhaps more obvious (and less subtly presented) in the Delphic Charioteer and the Caryatids, where robe arrangements echo column fluting, impart movement, and evoke a feeling of appropriate solidity.

Mavrikios goes on to show that all the elements of the Doric contribute to a downward movement and that horizontal curvature and entasis arose out of aesthetic necessity:

The shaft of the Doric column does not reach upward; it simply rises up. . . . It seems to reach plastically, for it has entasis; yet at the same time it seems to convey and distribute the weight downward, first of all due to this entasis . . . ¹

and secondly due to the free prolongation of the fluting down to the stylobate.

The significance of this argument is not that it negates what appears to be the generally accepted feeling that 'Greek temples soar up', only that it strengthens the notion that there is motion, both up and down. It reinforces the etymological significance of ἡ ἐντασις as tension or strain and the idea of plastic balance.²

¹Mavrikios, p.26

²Others have articulated the role of plasticity and balance but in a rather incidental way because they were concerned with other aspects: Lawrence, pp.172,304; Gruben, G., GTS, pp.312-13, though he makes no mention of entasis per se.

3'. The Column, the Canon and Human Proportions

The Greeks - and before them, the Egyptians - conceived of the column as emanating from human proportions. The Greeks went so far as to impart gender: masculine to the stout Doric and feminine to the slender Ionic. It is germane to any consideration of entasis as a ratio of some part of the whole to study for a moment at least the nature of the struggle for what Polycleitos termed a canon of symmetria in his sculpture. The illustrations will suggest rather than spell out the differences in the various canons and the effect these might have had on columnar proportions.

Vitruvius, it should be noted, spelled out which of the Greek orders were to be reserved for certain deities.¹ In the Renaissance, the Church would apply the principle to the hierarchy of saints and there was an extension of the use of columns in this way to most Christian and profane buildings.² Serlio's Regole generali di architettura.... sopra le cinque maniere degli edifici (published between 1537 and 1551) had temporarily, at least, caused the re-acceptance of the principle that individual orders of columns for certain architectural problems are pre-determined and are meaningless if applied otherwise. In France, the Netherlands and Germany especially the theory

¹Vitruvius, I, 2

²Wurtenberger, Franzsepp, Mannerism, Holt, Rinehart and Winston, New York, Chicago, San Francisco, 1963, pp.87-88.

was expanded by peculiar ideas about the special ethical principle involved in using the orders and columns which by now "were conceived of as sublime and valuable structures which had human proportions and even exhibited human characteristics".¹ Even Michelangelo had written that

one thing is certain: the limbs of architecture have their model in the limbs of men. Anyone who was, or is not, a good artist in the shaping of bodies and particularly not expert in anatomy, can understand nothing of this.²

The column was linked with the human figure even more so during the Mannerist period that followed the High Renaissance. Vincenzo Danti of Perugia never completed his book on 'perfect proportions' - (Volume I was published in 1567) - but he did leave us his contents page and it is very revealing. From the theory of proportions (Book I) he would have moved on to seven books on the anatomy of man, then a consideration of such factors as function of limbs, reasons conditioning outer shape, attitudes and gestures, physical symptoms of emotional states, until in Books XIV and XV he would have established the relationship of one part of architecture to another based on human proportions.³ It is astonishing that he should have prepared such a long preamble to the essential part of

¹ Wurtenberger, p.87.

² _____, p.68

³ _____, pp.50-51

his work. Who can doubt the effect of humanism - or the effect of the proportions of the human body - on architecture at this time? One can see the column and human figures directly compared and the sheer 'majesty of columns in themselves and in their setting'¹ in such works as Parmigianino's Madonna del Collo lungo.

Other works, such as Pellegrino Tibaldi's Wind God on an Entablature in the Palazzo Poggi in Bologna clearly show both the human figure and entasis from unusually daring vantage points. The virtuosity and almost acrobatic feats of the god go far beyond the conventions of normal bodily postures². Dare we suggest that herein is an explanation for the obvious entasis of the period, and of the painting? Might not what Vasari calls the di sotto in su (from below upwards) point of view not have been a factor in arriving at entasis even in ancient Greece? There is every indication that the natural taper of the columns when enhanced by the illusion of lines receding to a point in perspective necessitated the addition of entasis. One might even see a reverse effect at work in the human figures of the mannerist period: the entasis, or greatest bulge in the human profile is in the area of the hips. This is as true of Parmigianino's Madonna as it is of the later

¹Wurtenberger, p.74.

²_____, p.59.

Diane de Poitiers as the Goddess Diana by an artist of the Fontainebleau School. One is tempted to note more comparisons between these figures and the Caryatids of the Erechtheum, which, it can be argued, were executed during a Greek 'Mannerist' period.

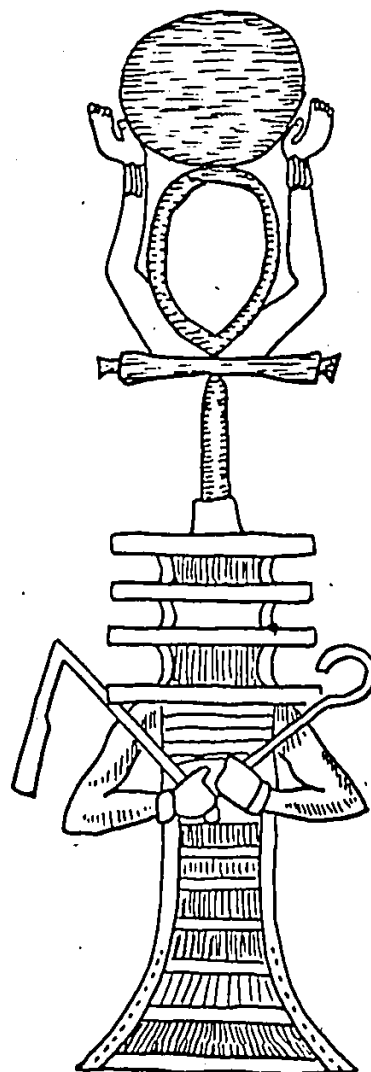
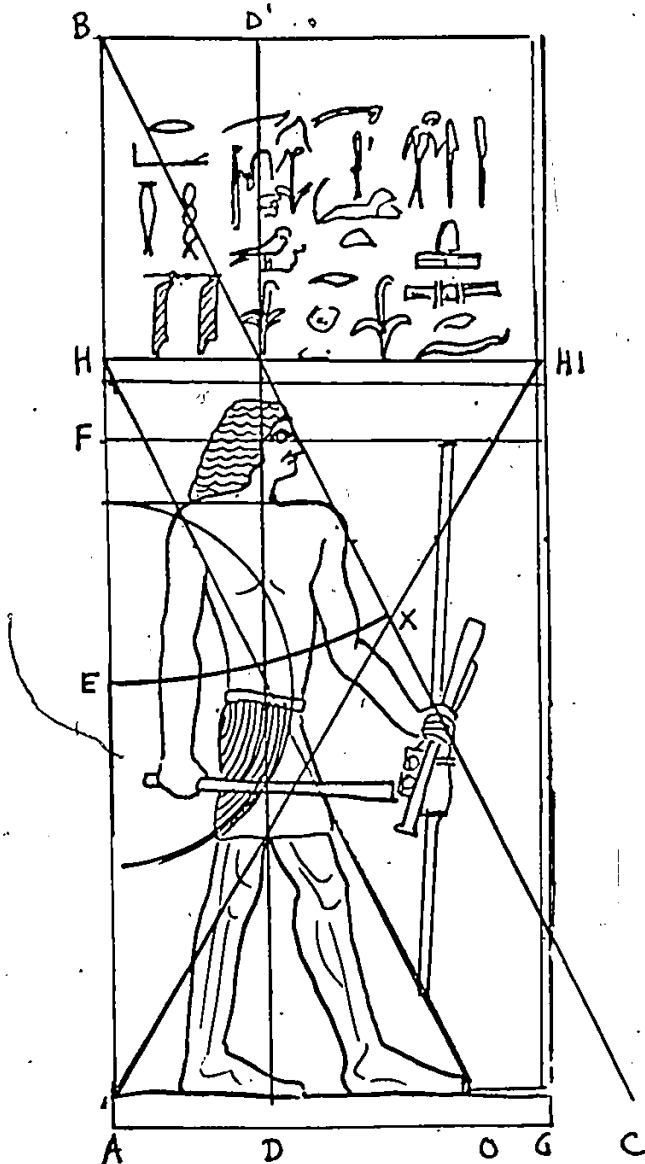
The illustrations on the following pages will show that there has been no great unanimity over the years on exactly what constitutes the ideal human type. It follows that there will be a proportionate lack of unanimity in applying any 'ideal' dimension to architecture and to columns. The search for a perfect formula related to the higher good - mathematics and numbers - continues. Pheidias, Polycleitos, Myron and Scopas differed in their canons; so did Michelangelo, Raphaello and Leonardo, yet Dürer and Henry Moore dared to draw inspiration - and their own canons - from their Greek and Roman predecessors. During the Age of Reason classicists and educators would devise simplistic rules for students to follow to produce lifeless images, and in our own times Le Corbusier would devise his own Modulor, a canon based on human proportions, to be used in erecting his avant-garde buildings. We may soon know just how far we have come to closing the circle we think started with the Greeks: Richard Tobin feels he has discovered the Canon of Polycleitos.¹ Can discovery of the formula for applying the canon to architecture be far behind?

¹Tobin, Richard, "The Canon of Polycleitos", AJA, 79, 1975, p.307.

The panel of Hesire (ca 2750 B.C.) (below) according to Else Christie Kielland: Geometry in Egyptian Art shows a concern with ϕ - the Golden Mean of the Greeks.

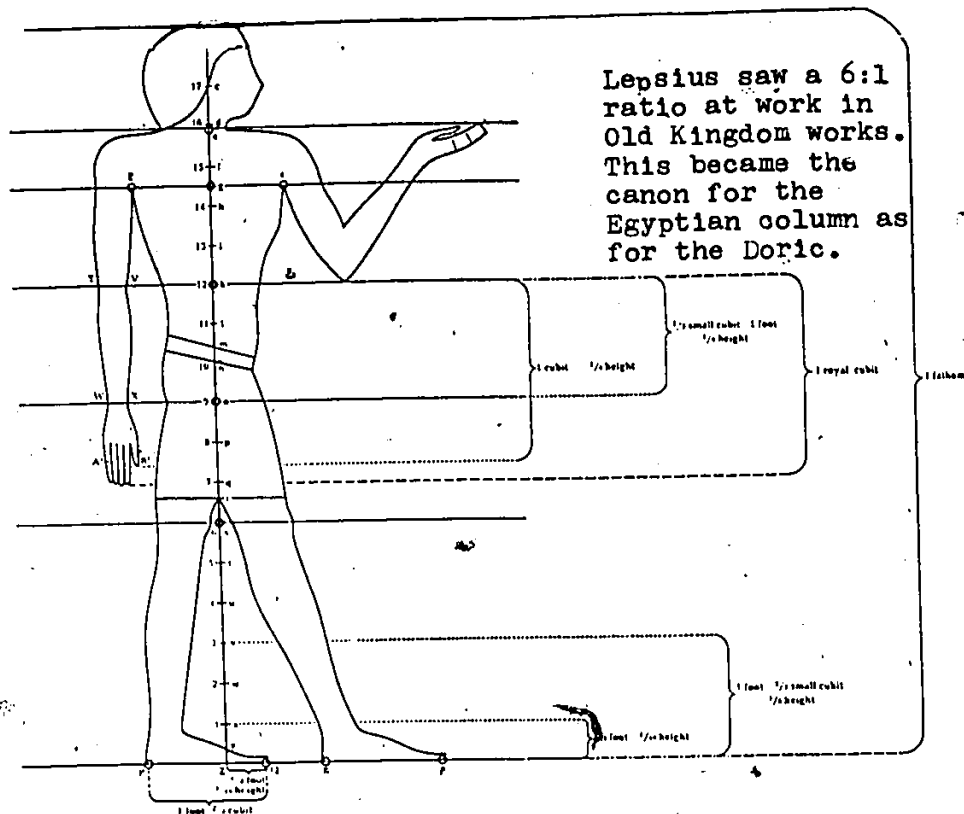
Hambidge and others have seen this 'dynamic symmetry' at work in Greek architecture.

(Sketch by the author from a photo in John Ivimy's The Sphinx and the Megaliths, Harper and Row, New York, 1975, p.194.)



The Djed Column (above) was worshipped as the personification of Osiris in ancient Egypt. To some it symbolizes the whole process of psychogenic evolution and the broad platforms (entasis?) are said to be the life force stretched out over the body which it animates in this world. (also from Ivimy, pages 38, 39 and 179.)

Fig. 48



EGYPTIAN CANON OF HUMAN PROPORTIONS: In the Old Kingdom the vertical axis passed through the navel. The dimensions and relations of different parts of the body are indicated by horizontal lines. From Iversen, after Lepsius

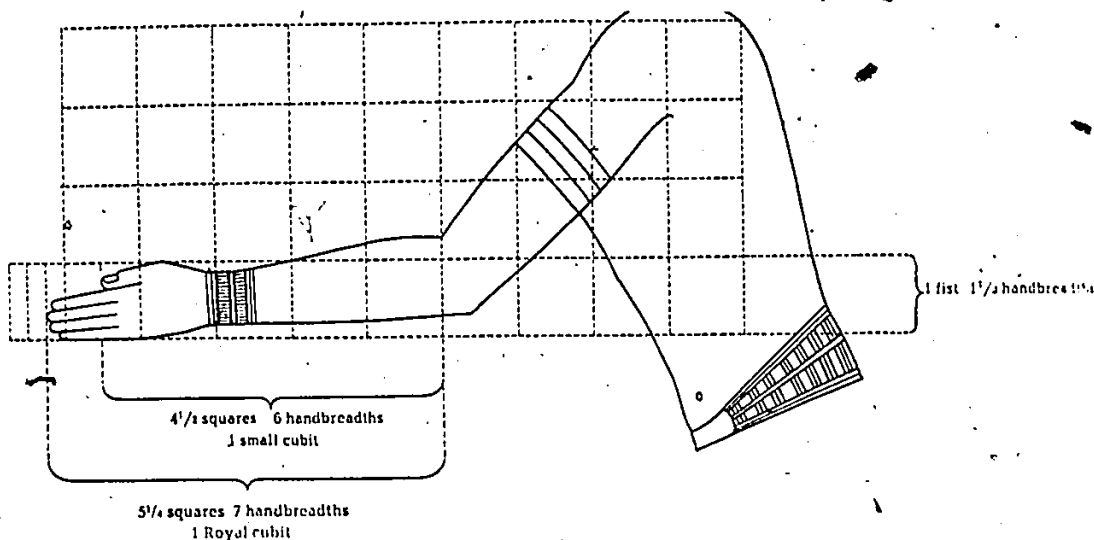
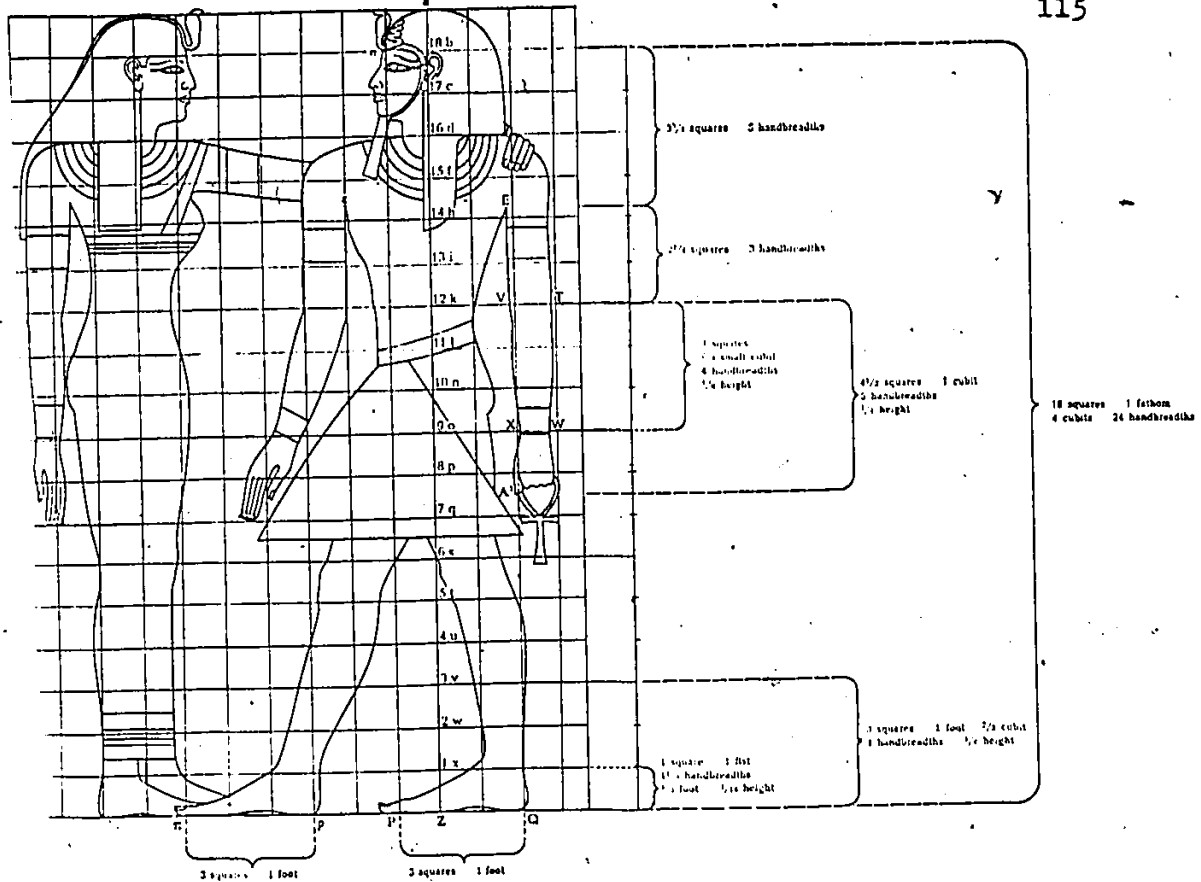


Fig. 49

THE FIST AS THE BASIC EGYPTIAN MODULE: The sides of the squared grid were identical with the fist (1 1/2 handbreadths). The "royal cubit" measured seven handbreadths (5 1/4 squares) from elbow joint to finger tips, the "small cubit" six handbreadths (4 1/2 squares) from elbow joint to the tip of the thumb. From Iversen, after Lepsius

(Reproduced from Figures 309 and 311 in Baldwin Smith's Egyptian Architecture, Cultural Expression.)



THE HUMAN BODY AND THE SQUARE GRID IN EGYPT: The square grid served to establish the absolute proportions of the human body. For instance, according to the "old canon," the human body measured eighteen squares (+ small cubits) from the soles of the feet to the forehead. From Iversen, after Lepsius

(The above is illustration 313 from Baldwin Smith.)

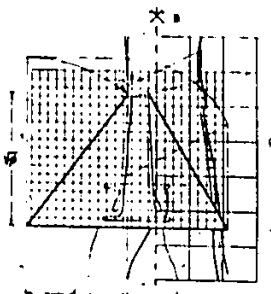
At right, the phallic significance of the figure is more obvious. Schwaller de Lubicz and Stecchini see the king as ϕ^2 split into a ϕ plus 1 proportion by the phallus. The arm gives a $6/5$ or $1.2 \times \phi^2$ proportion, or 3.1416 , or π . (from Stecchini, p.194.)

Abu Simbel features several reliefs of Rameses II with phallus erect as in the illustration. (MacQuitty, Wm., Abu Simbel, Putnam's Sons, New York, 1965., pp.33,115.)



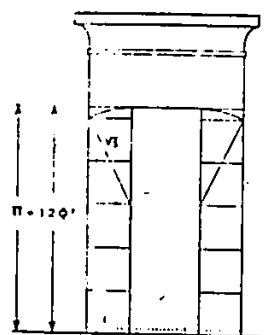
Fig. 50

The illustration at right (from Stecchini, p.195) shows how the same ratio is applied to architecture and (below) to royal kilts which have an obvious phallic connection. (also from Stecchini, p. 195).



Schwaller de Lubicz measured scores of triangular royal napkins and found that lower angles were invariably ϕ and $\sqrt{\phi}$.

Schwaller de Lubicz shows how the value of π correct to four decimals, or 3.1416, was incorporated into the great gate whose basic measurement was 1×2 .



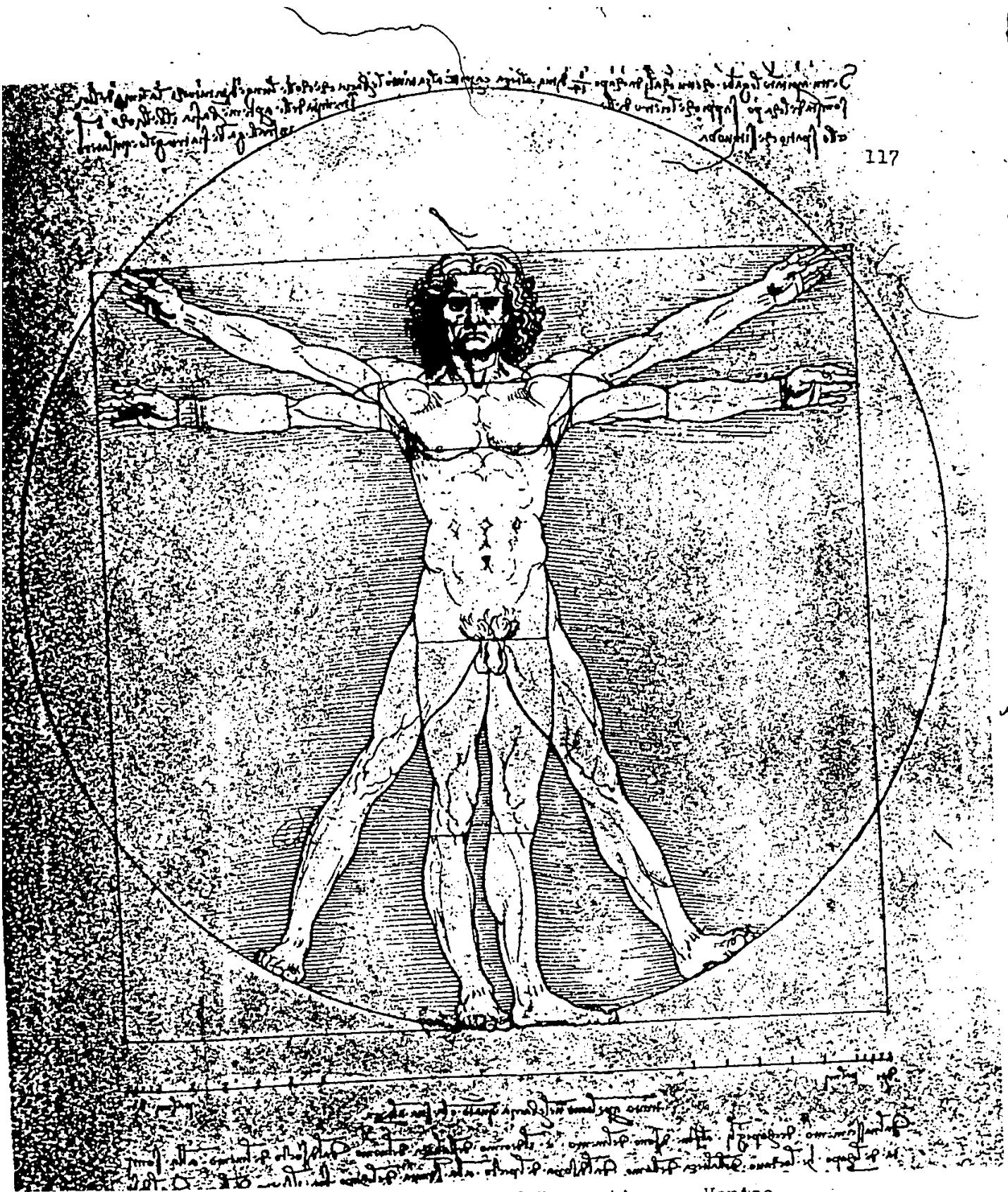
Schwaller also notes the coincidence that the Greeks adopted the symbol π , which looks like an Egyptian doorway, as their symbol for the relation of diameter to circumference. (Stecchini, p.195).

Polycleitos' Spearbearer was presumably the embodiment of his Canon. The figure was almost seven head lengths tall and much more elegant than the squat (6:1) Doric predecessors.

Richard Tobin has published a paper: "The Canon of Polycleitos" in *AJA*, Vol.79, 1975, in which he shows how the canon uses the small bone of the little finger as a key. The explanation has merit in that, like the Fibonacci series, there is both a linear and a volumar progression.



Fig. 51



Leonardo da Vinci's Canon of Proportions - Venice,
Academy of Fine Arts, detail from Leonardo da Vinci,
Reynal and Co., New York, 1956, p.446.
Vitruvius also suggested that the human
could fit inside a circle.

Fig. 52



Presumed portrait of Leonardo in Luca Pacioli's *Trattato de divina proportione*, Venice, 1509



Profile of Leonardo taken from Venice drawing

Fig. 53

Portraits show Leonardo's continuing interest in proportions, (from Leonardo da Vinci, pp.10,13).

The data he compiled is evidently so contradictory that a Leonardian canon of proportions cannot be arrived at. But then, perhaps Leonardo did not want to produce a strict canon. He wrote "And even if you should wish to make your figures according to one and the same measure, know that one will not be distinguished from the other, and this is not seen in nature.". Accordingly he set up various types and left it to the artist to choose the most graceful type to take his measurements from.¹



Proportions of human face - Self-portrait by Da Vinci - Turin, Royal Collection

Might not a similar philosophy have existed in Greece among sculptors and architects? This would account for the variance and vitality of Greek proportions - and entasis.

¹Biaggi, Carlo Felice, "Anatomy", Leonardo, Reynal, New York, 1956, p.447.

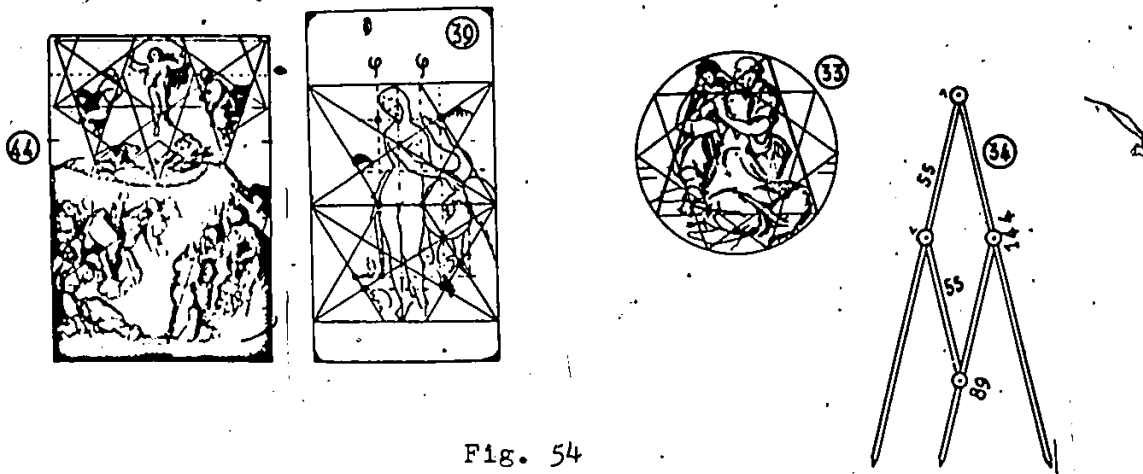
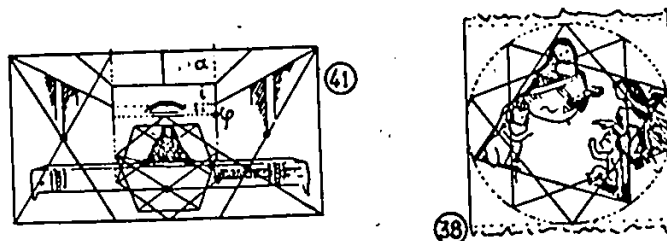


Fig. 54

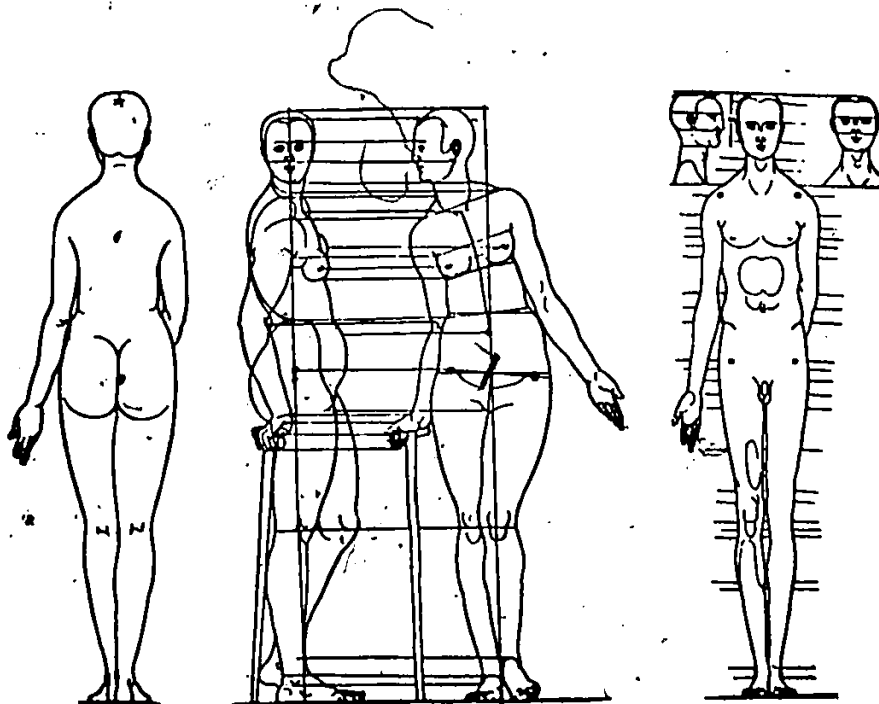


A Renaissance application of the Golden Section to painting is illustrated above. Funk-Hellet's analysis of a Michelangelo (33), Raphael (38, 44) and Leonardo da Vinci (39, 41). It should be noted that architecture was a proper subject for the artist to put behind a human, god or noble. The Golden Section Compass (34) with 55/89 relation is especially interesting.¹ It afforded a quick way of arriving at mathematically correct 'golden' ratios without the aid of mathematics. Might a similar instrument have been in use on the building site of a Greek temple?

(Leonardo used a similar instrument - indeed he used several parabolic, elliptic and 'reducing compasses' because he was weak on mathematics, but strong on instruments. His columns show entasis and his sketches show a concern for understanding stress in columns. He understood the importance of added width, rather than height, in a column.² Might he have considered the mechanical advantage of entasis?

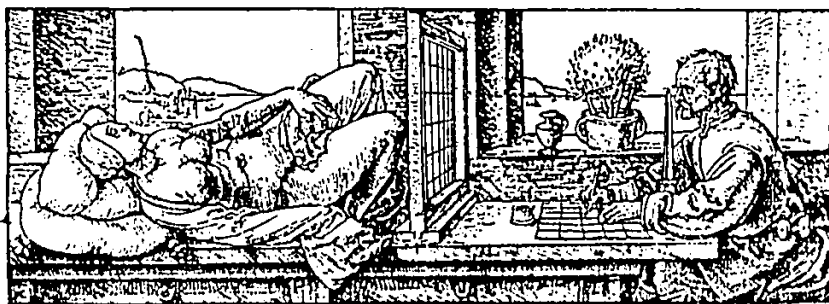
¹Tompkins, Peter, Secrets of the Great Pyramid, Harper and Row, London, 1971, p. 193.

²Cisoti, Umberto, "The Mathematics of Leonardo", Leonardo da Vinci, Reynal & Co., New York, 1956, pp.201-02.



A The figures above, after Albrecht Dürer, show his canon of proportions for the female, at left, and for the male at right. The Diane de Poitiers type of shape is peculiar to the mannerist period. The Dürer male is certainly less heroic than the Polycleitos male. (Sketches from the author's notebook.)

Fig. 55



THE SQUARE GRID OF THE RENAISSANCE: Artist drawing a reclining woman in perspective: woodcut by Dürer. The square grid which Alberti invented in the early fifteenth century assisted in the perspective reproduction of objects as they appear.

B. Smith discusses the square grid of Dürer in his consideration of Egyptian use of the same grid in the Old Kingdom. Other factors, notably a consideration with depth, vanishing point perspective and the invention of the camera obscura were now at play. (Illustration 312 from Baldwin Smith.)

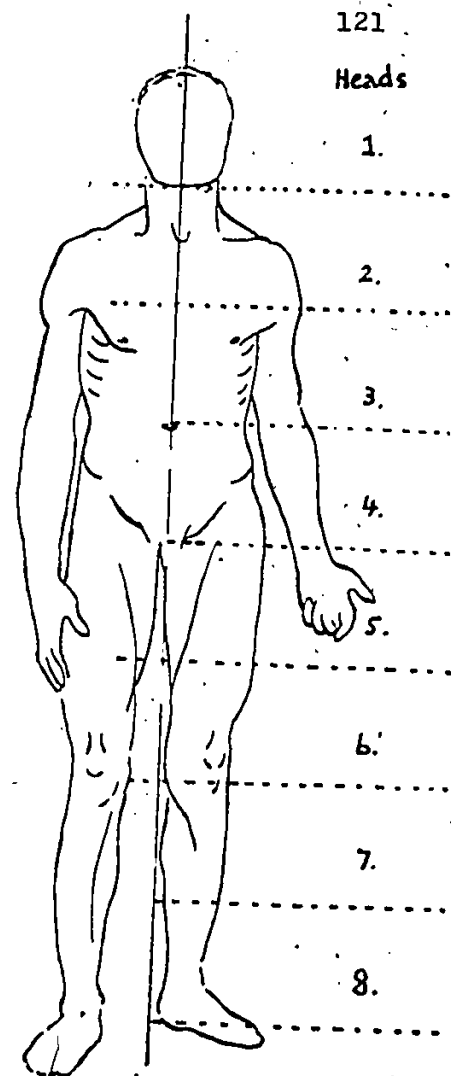
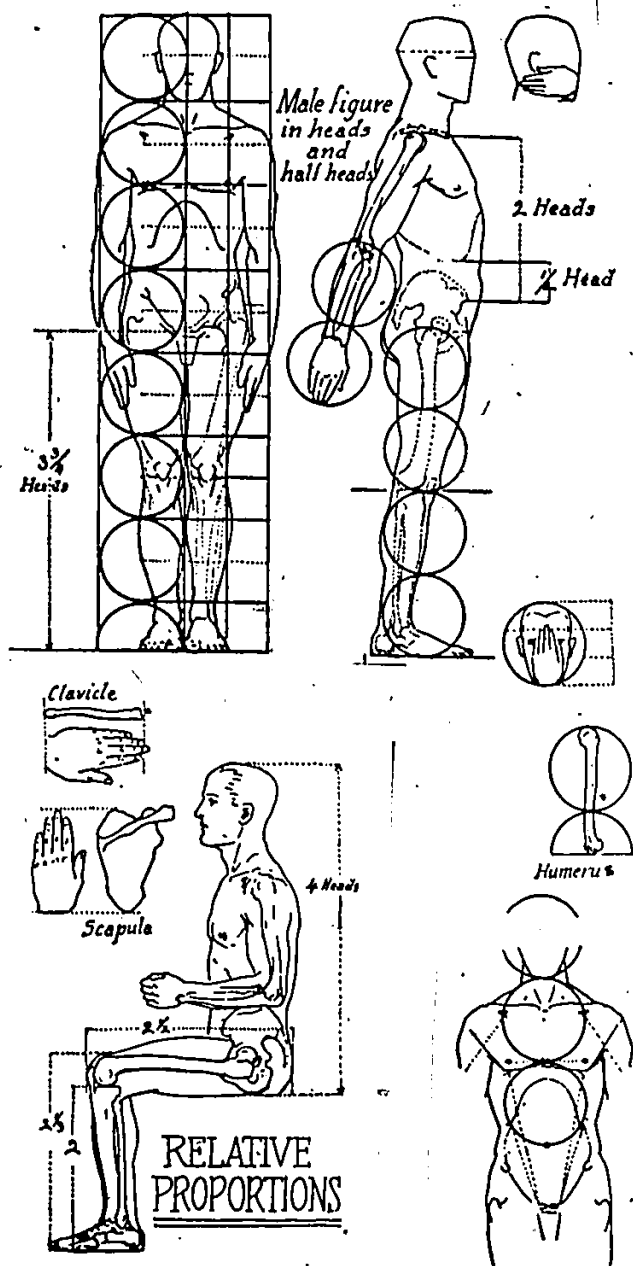


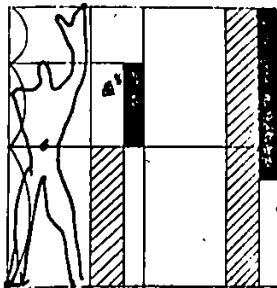
Fig. 56

The illustration above shows human proportions based on $7\frac{1}{2}$ head lengths. (Perard, Victor, Anatomy and Drawing, Kingsport Press, Kingsport, Tennessee, 1936, 1946, p.3.)

Compare the top left with the above figure based on 8:1 head lengths. (from the author's sketchbook.)

The Fibonacci series is shown graphically. Each new unit grows larger or smaller by maintaining a ϕ relationship between units; each new number is the sum of the previous two, e.g. 1-2-3-5-8-13-21. . . . Fibonacci, who is credited with introducing the Hindu system of numerals into Europe around 1200 A.D. learned the series in Egypt. (Illustration is from Tompkins, p. 192.)

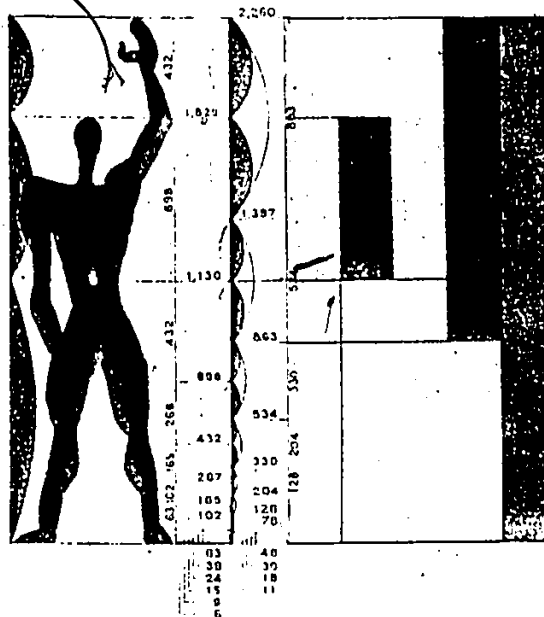
This mathematical grid, based on the Golden Section, was to become the backbone of the architectural system developed by the great French architect Le Corbusier for his construction of anything from the United Nations building in New York to the closets in a bathroom.



Le Corbusier's "modulor" based on the ϕ relation in the human body.

Le Corbusier developed his MODULOR between 1946 and the mid '50's. He based it on a spiral that is not unlike the vertical projection of a helix sometimes used in entasis. (Le Corbusier Creation is a Patient Search, Praeger, New York, Washington, 1960, pp.158-159.)

Fig. 57



Polycleitos is said to have told his contemporaries that his Doryphoros (Spearbearer) was composed according to a canon, that every line from the toes to the last hair on the head was calculated and that every surface depended on the scratch of a fingernail. There is a suggestion here that his canon was both linear and geometrical - rather like Le Corbusier's Modulor.

A mathematician-sculptor recently announced that he had discovered the canon of Polycleitos and that the 'key' was in the dimensions of the third or distal phalange of the little finger.¹

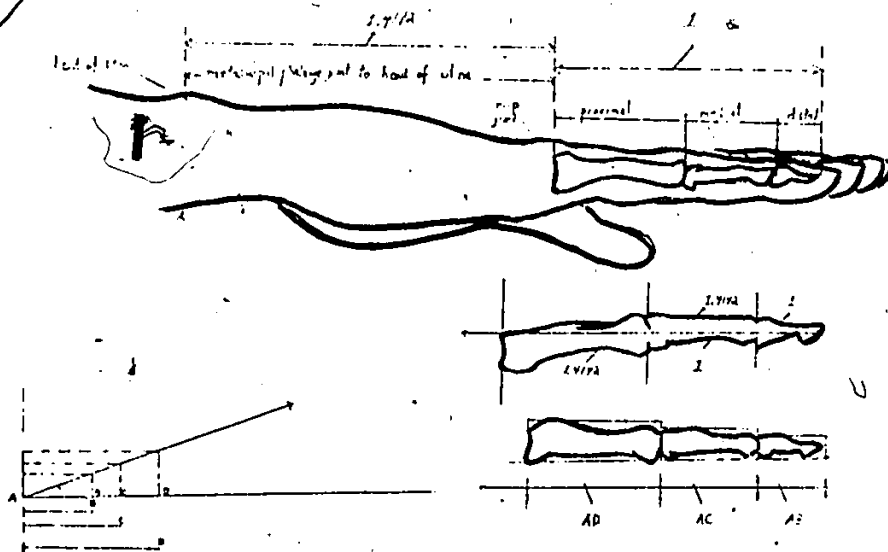
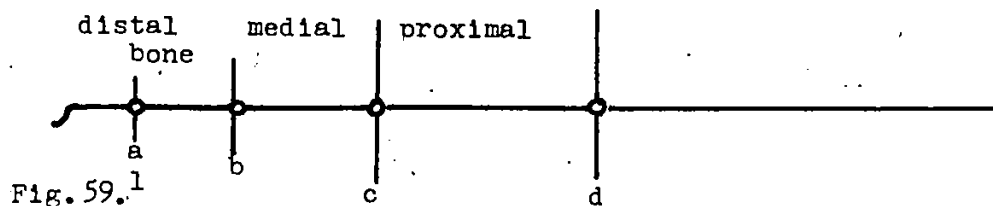


Fig. 58

¹Tobin, Richard, "The Canon of Polycleitos", AJA, 79, 1975, p.308.

Having established a geometric unit generating a series of proportions based on one constant ratio (the length of each spatial number with the diagonal of its square, or 1:1.4142) the sculptor had but to use a cord with knots to record the heights or lengths of parts.



Kenneth Clark has written:

I have said that a system of mathematical proportion appears in the nude long before the element of beauty; Polycleitos codified it and made it, no doubt, more elaborate . . .

Besides these problems of balance and proportions Polycleitos set himself to perfect the integral structure of the torso. He recognized that it allowed for the creation of a sculptural unit in which the position of humps and hollows evokes some memory and yet can be made harmonious by variations and emphasis.²

If the sculptor could achieve balance and proportion by means of a canon but impart vitality through variation, emphasis and native genius, there is no reason not to believe that the architect (who might also be a sculptor in Periclean or in Renaissance times) did not do the same thing. Might he not have proceeded like the harpedonatae of old with his

¹Tobin, p.310.

²Clark, Kenneth, The Nude, A Study in Ideal Form, Doubleday, New York, 1959, p.67.

gnomon or rope canon to give important ratios and proportions; (the former relates two, the latter three or more).

Transitions would be made going from length to width and ratios would be hard to analyse, partly because of the geometry involved, partly because of the transitions, and partly because the masons 'evoked memory' or made the whole harmonious by 'variations and emphasis'....refinements.... necessitated by the material or situation at hand, the individuality of the worker and the Greek dislike for sheer monotony.

In this last regard, we must remember that Leonardo sought ideal types but warned against slavishly adhering to the canon. Le Corbusier firmly believed that architecture was proportion, yet he could alter his Modulor based on a 5'7" average Frenchman when he realized that detectives in novels were generally 6' tall. His should be the last word in this discussion:

... the Parthenon, the Indian temples, and the cathedrals were all built according to precise measures which constituted a code, a coherent system: a system which proclaimed an essential unity. Primitive men at all times and in all places, as also the bearers of high civilizations, Egyptian, Chaldean, Greek, all these have built and, by that token, measured. What were the tools they used? They were eternal and enduring, precious because they were linked to the human person. The names of these tools were: elbow (cubit), finger (digit), thumb (inch), foot, pace, and so on...Let us say it at once: they formed an integral part of the human body, and for that reason

they were fit to serve as measures for the huts, the houses, and the temples that had to be built.

More than that: they were infinitely rich and subtle because they formed part of the mathematics of the human body, gracious, elegant and firm, the source of the harmony which moves us: beauty (appreciated, let it be understood, by the human eye in accordance with a well-understood human concept; there cannot and never could be another criterion).

The elbow, the pace, the foot and the thumb were and still are both the prehistoric and the modern tool of man.

The Parthenon, the Indian temples and the cathedrals, the huts and the houses, were all built in certain particular places: Greece, Asia, Europe, and so forth. There was no need for any unification of measures. As the Viking is taller than the Phoenician so the Nordic foot and inch had no need to be adapted to the build of the Phoenician, or vice versa.¹

Perhaps this is why there is no one formula for entasis in Greek columns. Times changed and they changed with them. Canons varied and were applied not slavishly but to reflect the creative genius of the architect.

"The Modulor [or Canon] makes the bad difficult and the good easy; this weapon shoots straight."²

¹Jordan, Robert Fumeaux, Le Corbusier, J.M. Dent & Sons, London, 1972, pp.113-114.

²_____, p.106. (Also of interest is the importance Mannerist painters such as Parmigianino placed on proportions and ratios in both the human figure and the column; they used the 2:1 relationship often favored by the ancient Egyptians and Greeks.)

REFINEMENTS, ESPECIALLY THE
HORIZONTAL CURVATURE

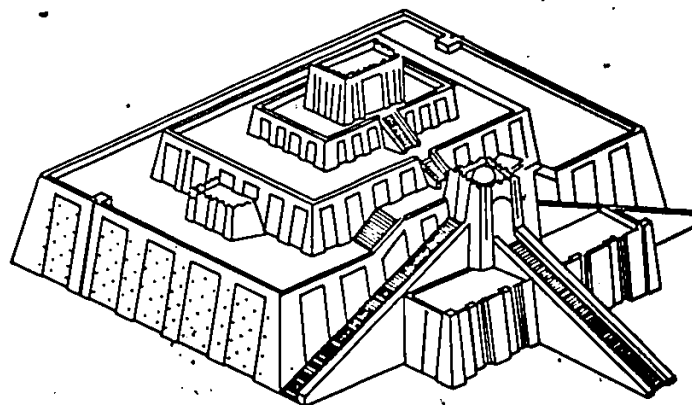
It was sometimes the wont of ancients to impart a curve to plan, wall, floor, substructure or superstructural elements. The next five pages illustrate Mesopotamian and Egyptian examples and cite sources. These precedents are important to any consideration of the horizontal curvature of Greek temples because the purpose of the Hellenic curve is sometimes said to be simply to serve to carry away rainwater. Is it likely that the same reason was responsible for the curve in buildings in the more arid Near Eastern countries?

The level of the stylobate must be increased along the middle by the scamilli impares; for if it is perfectly level, it will look to the eye as though it were hollowed a little. At the end of this book a figure will be found, with a description showing how scamilli may be made to suit the purpose.¹

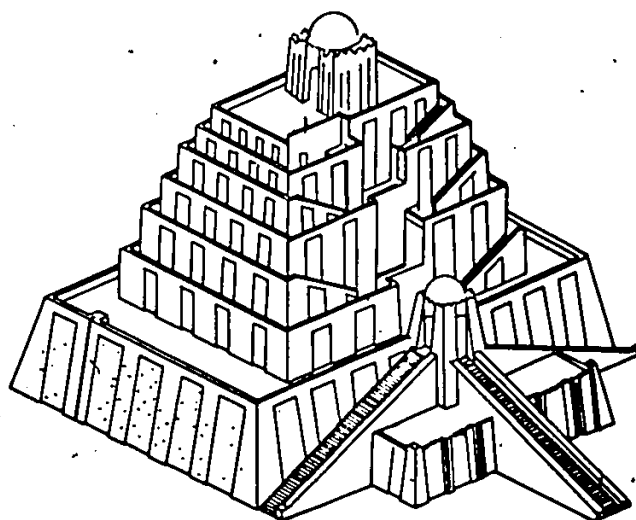
Vitruvius offers another reason - the countering of a disagreeable illusion. There are, perhaps, four reasons which we can classify as optical or illusory, aesthetic, traditional and practical. A brief consideration of each follows.²

¹Vitruvius III, 4.

²We shall not concern ourselves with the great dispute over the existence of this curvature since scholars such as Durm and Bötticher have been refuted by Dinsmoor and others, and, in any case, the existence of curvature was strongly denied only before it was discovered in Egypt and elsewhere.



a.



b.

Fig. 60. The entasis principle at work in Mesopotamia

There was an imperceptibly curved line in every wall and in the superstructure at Ur. (Wellard, James, Babylon, Schocken, New York, 1974, p.91.)

Fig. a is a reconstruction of the ziggurat of Urnammu of the Third Dynasty, c. 2050 B.C. Fig. b. is the same ziggurat as remodelled by Nabonidus in the sixth century B.C. Both figures from Cleator, P.E., Archaeology in the making, Robt. Hale Ltd., London, 1976, pp.138-139.

The ziggurat of Babylon, says Stecchini, would have been perfect trigonometrically if the height of the first three steps had been as originally conceived: 30, 48 and 55 1/2 degrees. But the Babylonians raised the first step to 33°, the approximate parallel of Babylon.

The cuneiform description of the ziggurat, known as the Smith tablet, specifically indicates that each level of the ziggurat has an area corresponding to standard units of land surface. Particularly important in Mesopotamian land surveying was the square with a side of 60 double cubits—the surface of the third step.

The slope angles at various heights also give important angles, such as $\sqrt{5} - 1$, which is also incorporated into the Great Pyramid. Such triangles, and the number $\sqrt{5} - 1$ (in common practice taken as the magic series 1-2-3) were fundamental in the operations of land surveying.

The third, fourth and fifth steps of the ziggurat make triangles with sides related as the Pythagorean 3-4-5 triangle.

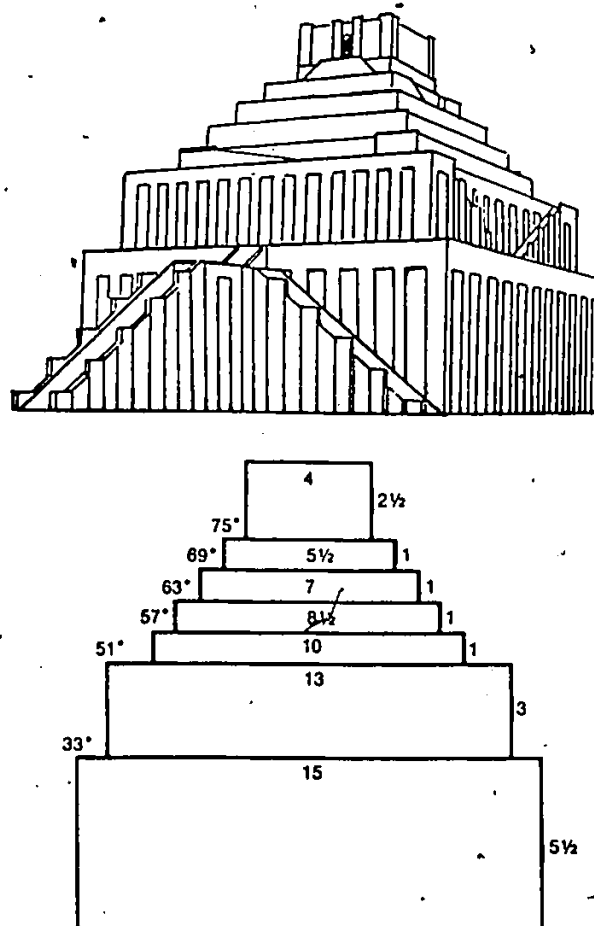


Fig.61.

Metrologists and numerologists see significance in the dimensions of the ziggurats which are also of special interest to mathematicians and astro-archaeologists.

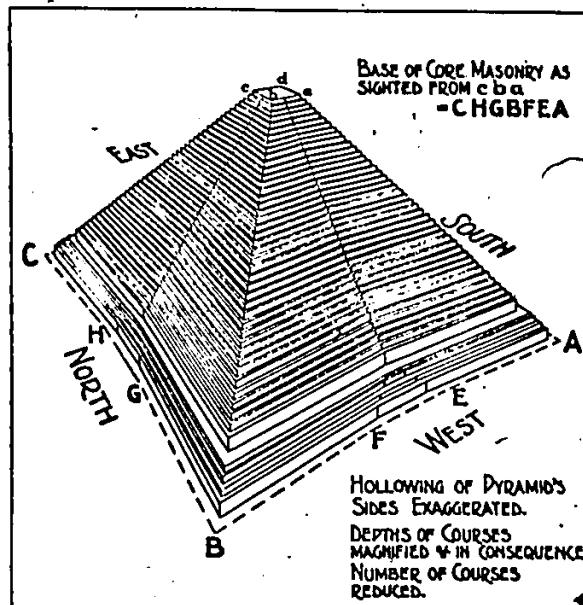
Besides this suggestion of hermetic knowledge - which extends to the dimensions of columns and entasis - the diagram and excerpt reproduced above are important for their allusion to the Pyramids which also have sides that are not perfectly straight. (Figure from Tompkins, P., Secrets of the Great Pyramid, Harper & Row, London, 1971, p.187.)

Sir Flinders Petrie noted a distinct hollowing of the core masonry in the central portion of each face of the Pyramid. Though the hollowing amounts to as much as 37 inches on the north face, it is not directly observable unless special lines of sight are taken.

Petrie found no evidence of hollowing along the lower-level casing stones, running along the base of the Pyramid, which have now been completely uncovered.

A recent survey by two Italian scholars, Maragloglio and Rinaldi, indicates the casing stones above the base line may have been slightly sloped toward a central line.

Davidson's plan of the base of the Pyramid, showing three different ways of measuring the year's length.



CONSTRUCTION OF THE GREAT PYRAMID'S BASE.

(If hollowing-in of core masonry GREATLY EXAGGERATED to show effect.)

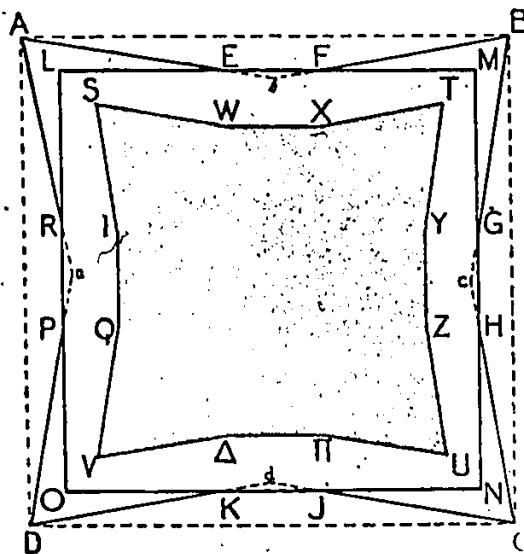


Fig. 62.

This page (115) also from Tompkins, Secrets of the Great Pyramid, shows that the entasis principle was in use and may have served a utilitarian purpose.

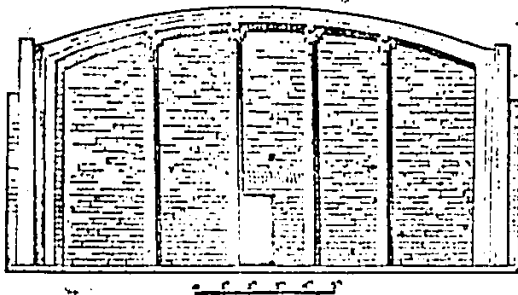


Fig. 63.a. the restored façade of the Southern Palace of the Step Pyramid at Sakkara complex. Smith says there is no doubt the roof line was curved. (Smith, Baldwin, Egyptian Architecture, Cultural Expression, American Life Foundation, New York, 1968, pp. 74-75.)

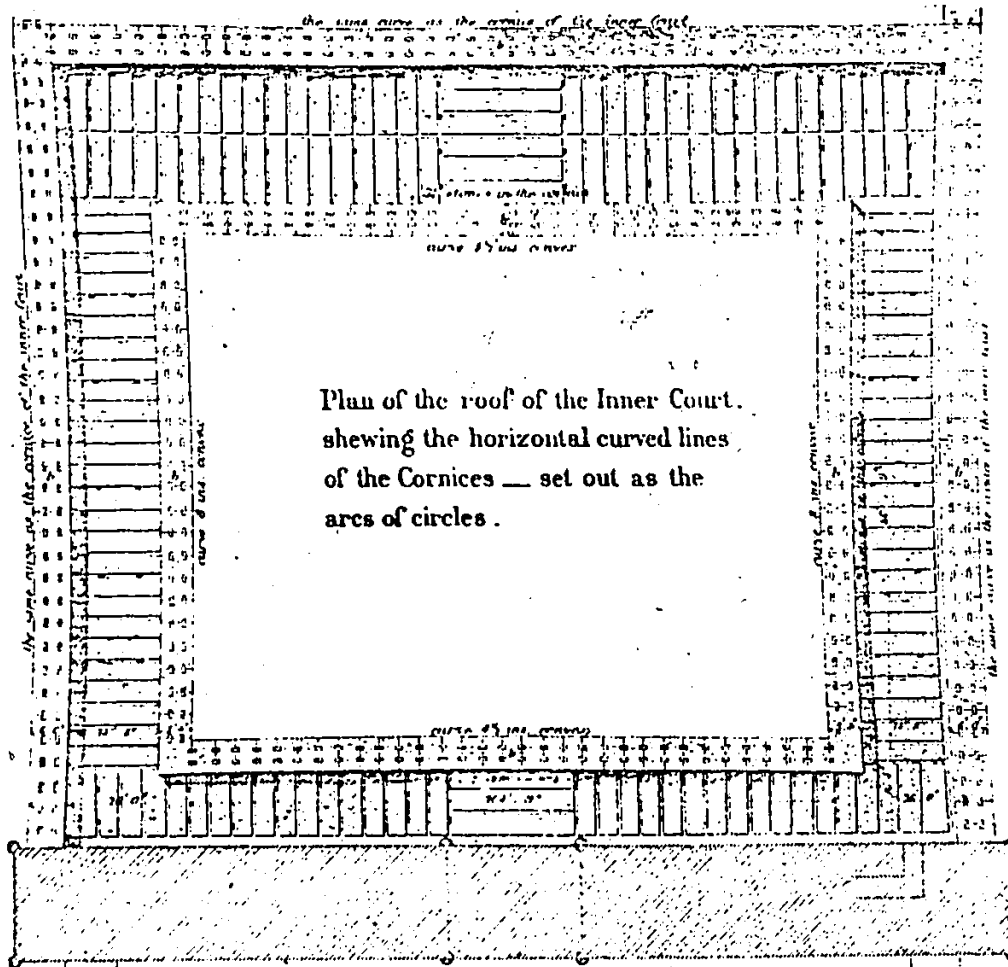


Fig. 63 Fig. b. Plan of the Roof of the Second Temple Court at Medinet Habou.

From Pennethorne's "Geometry and Optics of the Ancients." Showing curves in plan of $4\frac{1}{4}$ inches convexity on the long sides of the court (101 feet 9 inches) and of 8 inches convexity on the short sides (80 feet 9 inches).

(reproduced from Goodyear, W.H., Greek Refinements, Yale, London, 1912, p.36.)

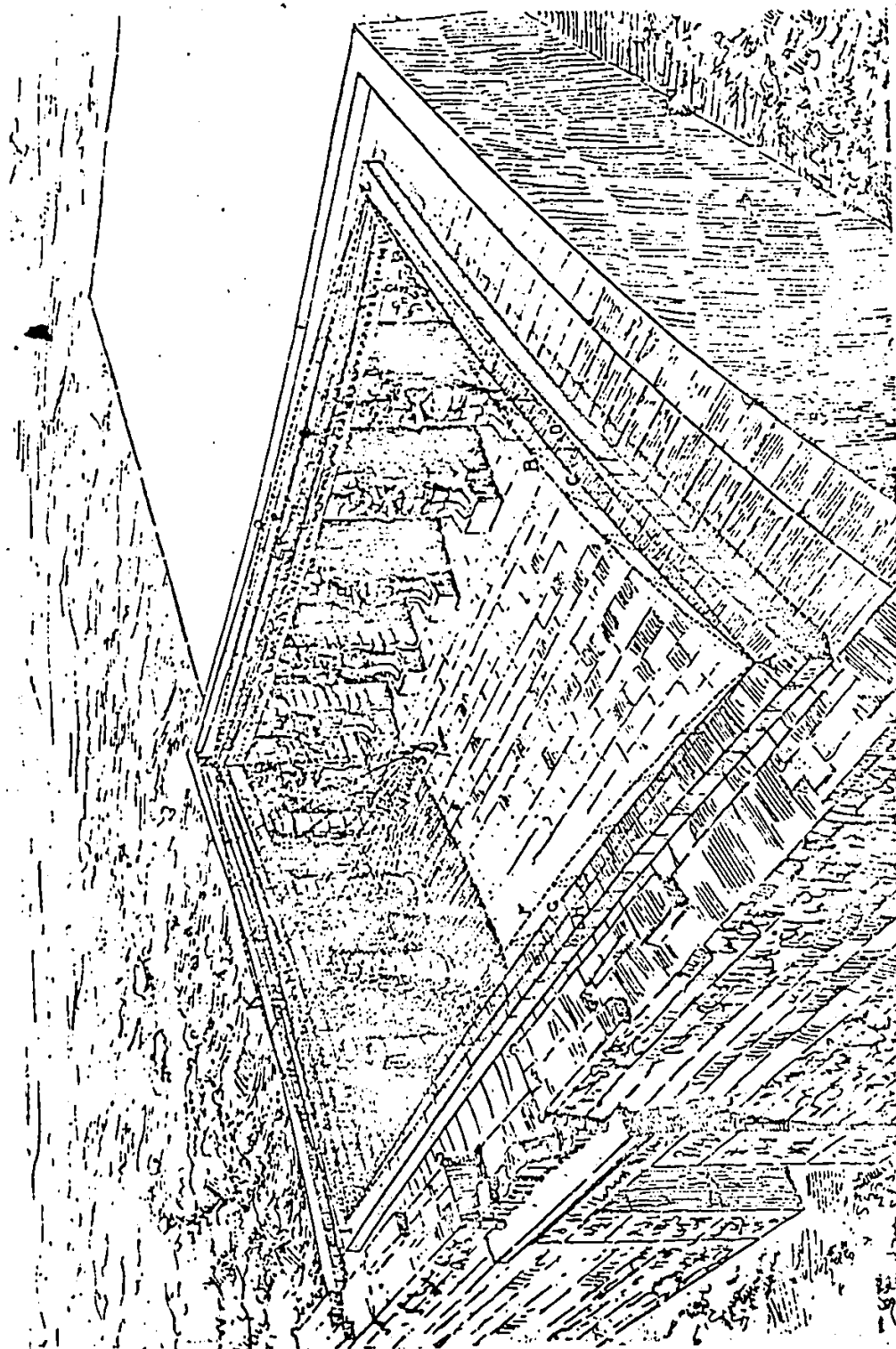


Fig. 64 Curves in Plan of the Second Temple Court at Medinet Habou. Thirteenth Century B.C. Bird's-eye View. The dotted-lines of curvature represent the optical effect from the court interior, as being that of rising curves in elevation. See Appendix A. (reproduced from Goodyear, Greek Refinements, p. 34.)

The first Greek attempts at horizontal curvature were apparently at Corinth where the solid rock foundation was also cut into to accommodate the curve of the stereobate. The Parthenon - and before it the Hecatompedon and the Old Temple of Athena - have been shown to have a curved stereobate. The Parthenon's corners were actually cut into the older foundations which were also curved.

It may be here observed that the several courses of the basement which we have shown to have belonged to the earlier temple, as well as those of the stylobate, are built in curved lines; that is, the line shown by each horizontal joint on the face of the wall is a plane curve, and rises a little in the middle from an imaginary straight line drawn from one of its extreme points to the other.¹

Curves were also imparted to the architrave and to the raking cornices as the diagrams on the next few pages will illustrate. Curves in plan such as are said to exist in some Greek temples may sometimes be attributed to confusion caused by working with photographs.² On the other hand, Goodyear vouches for curve in plan in the flanks of the Basilica at Paestum and the author took the picture on page 134 which clearly shows that there is today a marked curve in the side of the Temple of Apollo at Delphi. This latter, however, is very probably the result of landslides and earth movement.

¹ Penrose, p.20.

² Goodyear admits to making this error and to missing curve in plan when studying the Basilica at Paestum. (Goodyear, p.126.)

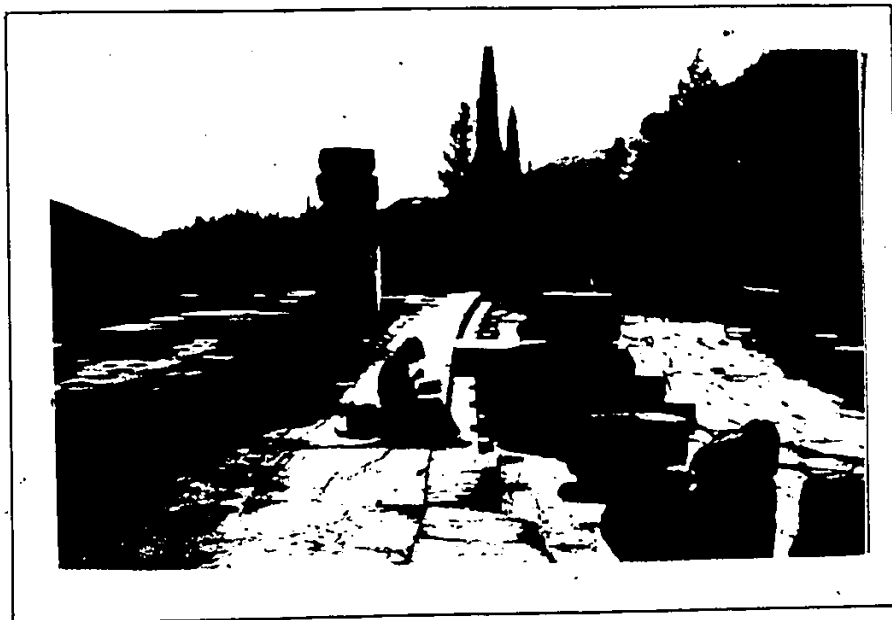


Fig. 65.

Curvature in plan is obvious in this picture of the flank of the Temple of Apollo that is beside the hill at Delphi. Was man or nature responsible? (Photograph by the author)

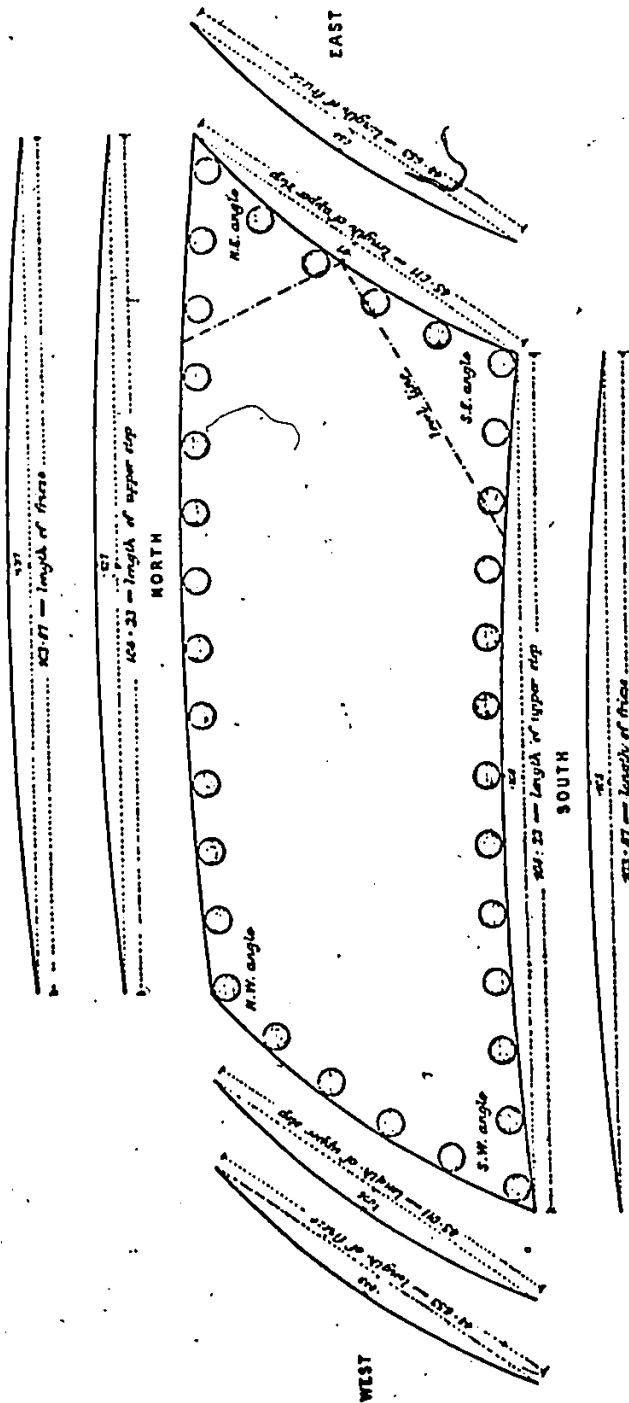
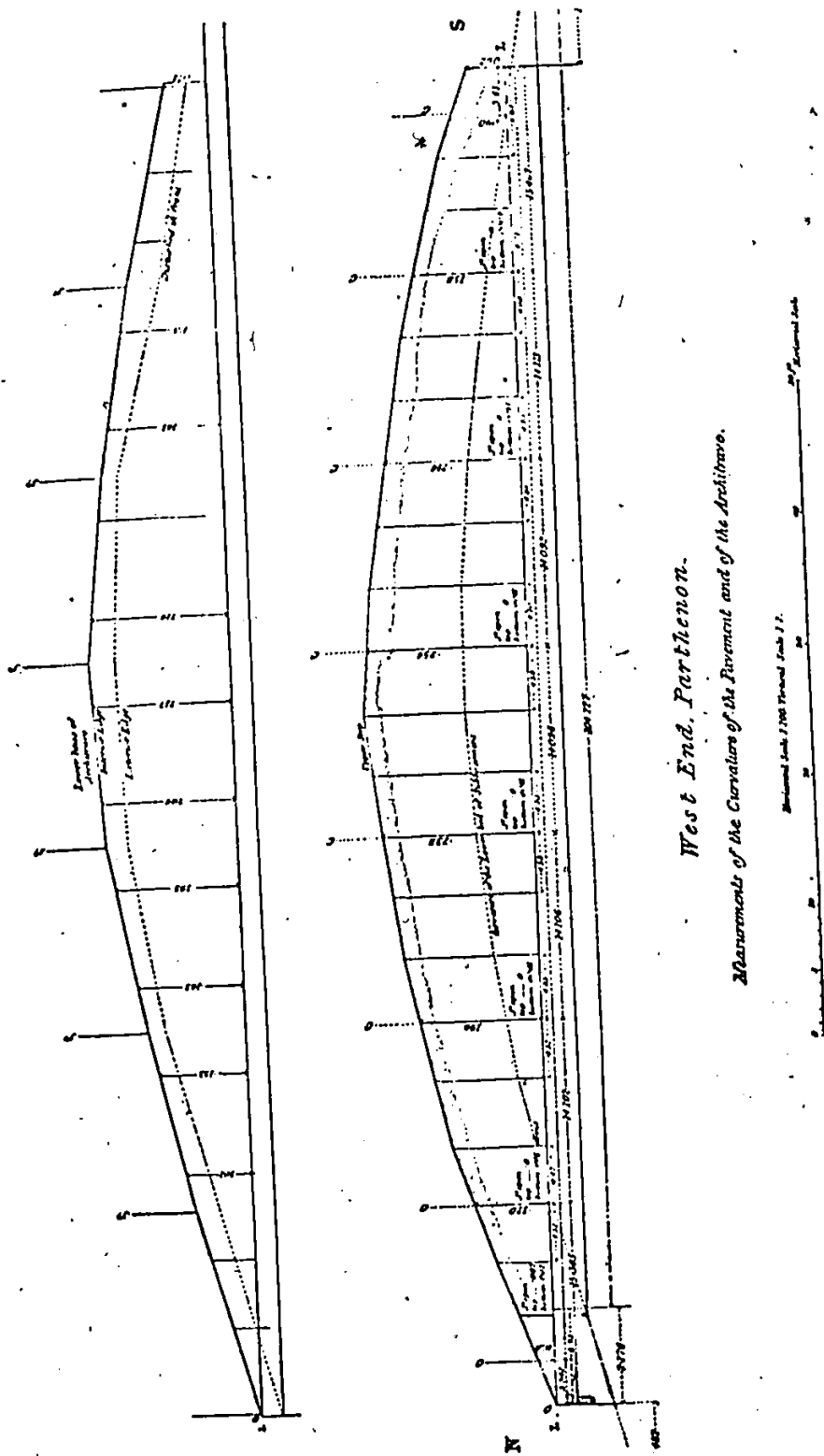


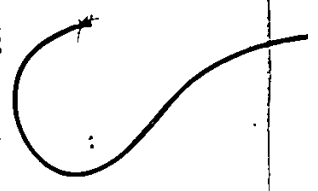
Fig. 66 Curves of the Thesum at Athens. From Pennethorne, Figure 3, Plate III, Part III. Showing his method of representing the Greek curvature by exaggerated drawing. The measurements are borrowed from Penrose. (Reproduced from Goodyear, Greek Refinements, p. 11.) (This diagram is reproduced in part by Dinsmoor, AAG, p. 167.)



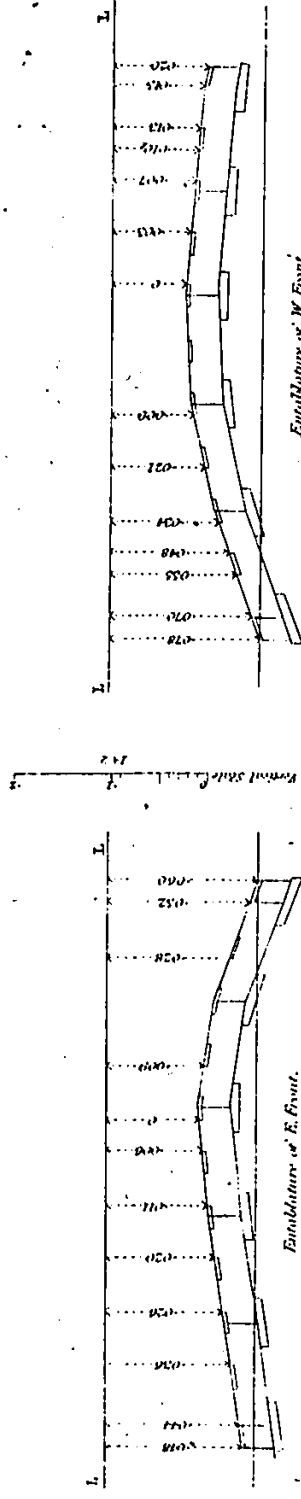
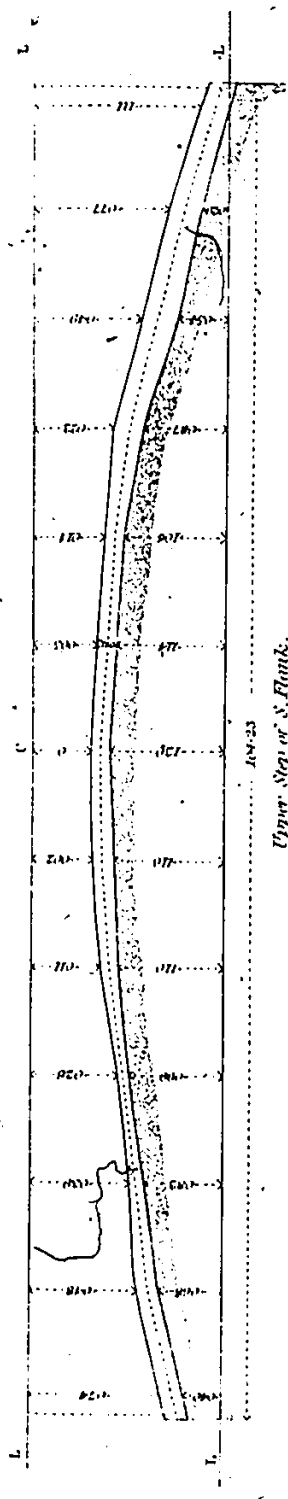
West End, Parthenon.
Measurements of the Curvature of the Pavement and of the Architrave.

Fig. 67.

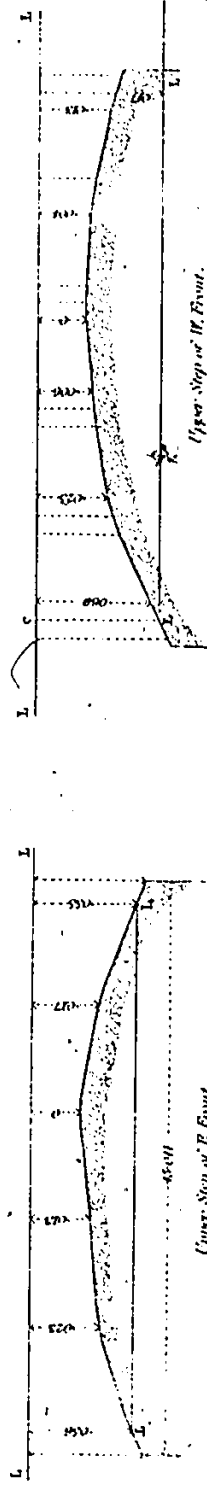
From Plate XI of "The Principles of Athenian Architecture." The curves are exaggerated fifty times in relation to the horizontal line.



Entablature of S. Flank.



Entablature of W. Flank.



Engendered Sections of the Curvatures of the Temple of Theoculus.



FIG. 68.

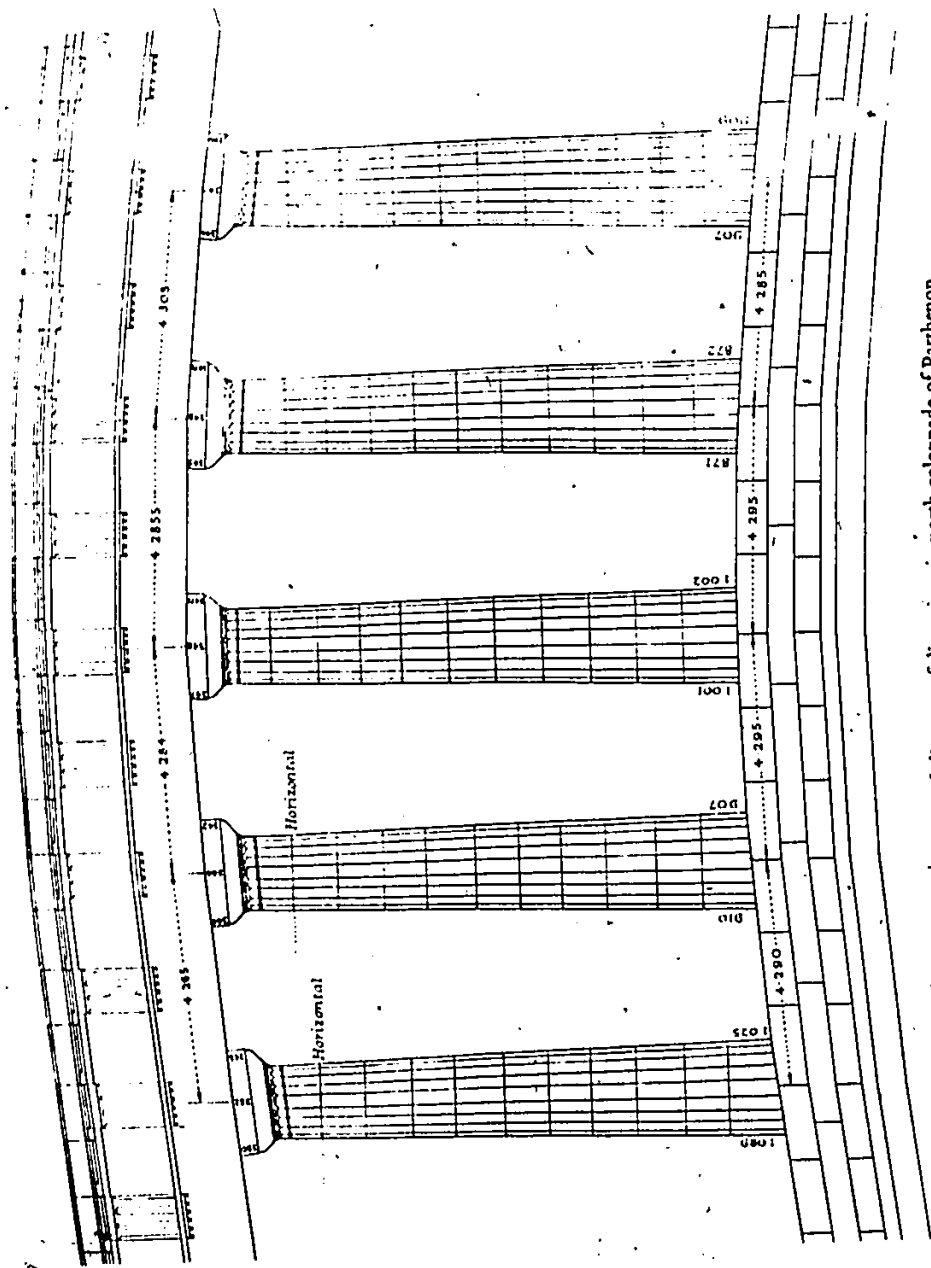


Figure 98. Exaggerated diagram of distortions in north colonnade of Parthenon

(from Lawrence, p.173)

Fig. 69.

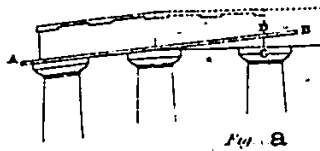


Fig. 70a

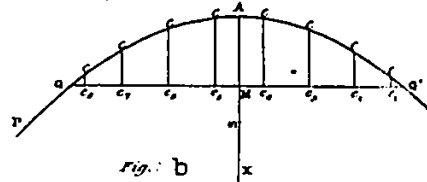
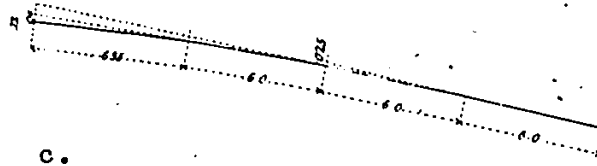


Fig. 70b

Fig. 70. a) represents the technique for showing how horizontal curvature in the base is mirrored in the architrave or vice versa.

b) shows the diagram to which Penrose reduced his measurements.

Both figures are from Penrose (Plate 10) and show the East end of the Parthenon.



c.

Fig. 70c shows the curve of the Pediment of the Theseum or Hephaistion, east portico. (Penrose, Plate 36)

Books touching on photography and its history credit the ancient Greeks with a knowledge of the principles of the pinhole camera.¹ But together with their knowledge that light travelled in a straight line into the eye (and/or out of it) they knew that the back of the eye was circular so that a straight line fell on a curved surface, as illustrated below:

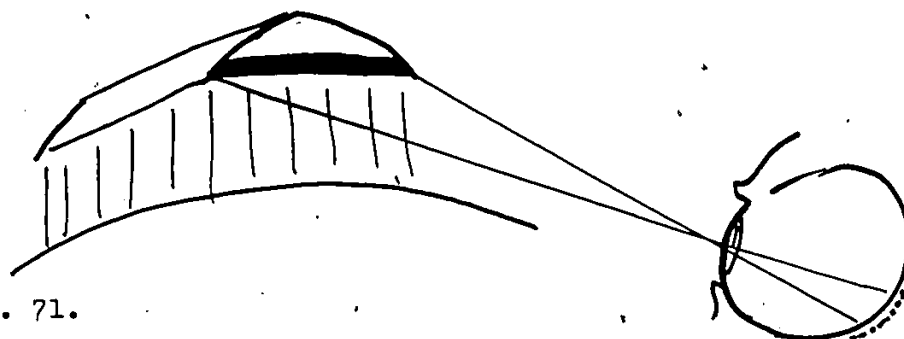


Fig. 71.

It might well be that this theory had something to do with their wanting to bend a straight line to make it appear straight to the eye. A simple experiment with a pinhole camera and film held in a concave position will show that straight lines above the line of vision will curve up (down in the inverted picture in the camera) and that straight lines below the line of vision (assuming they are perpendicular to the line of sight) will appear to bend the opposite way. The same effect might be illustrated by comparing two sketches showing vanishing point perspective:

¹ Lorente, J.A.D., Film, The Lens and You, Ontario Ministry of Education, Toronto, 1976, Ch.10, pp.1,2. Davis, Phil, Photography, 2nd ed., Wm. C. Brown, Dubuque, Iowa, 1972, p.1.; Bloomer, Carolyn M., Principles of Visual Perception, Van Nostrand Reinhold Co., N.Y. Cincinnati, Toronto, London, Melbourne, 1976, p.92.

Fig. 72

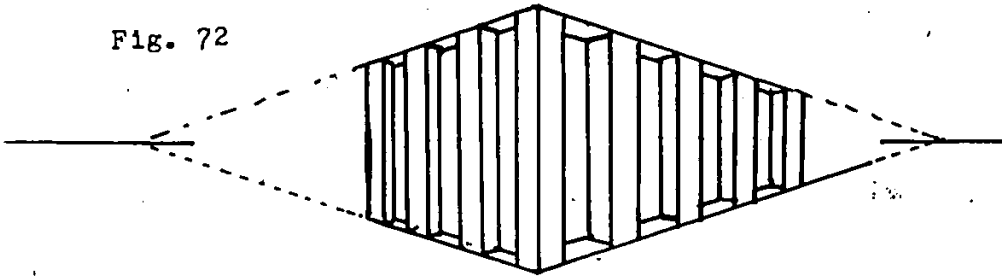


Fig. 72a) shows the pillars as they are usually seen in two-point vanishing perspective. We have been conditioned for five hundred years to accept this as accurate.¹

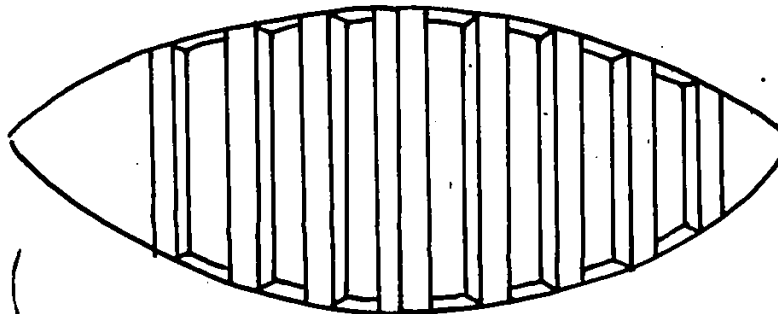


Fig. 72b) is more accurate a representation. Diagrams such as a) and b) have been used by Hauck and Levy.²

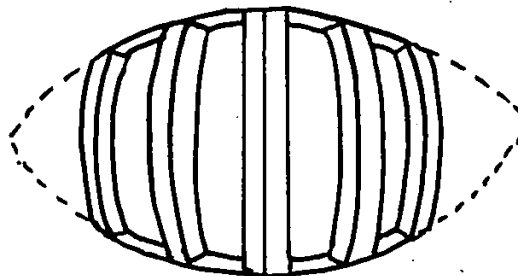


Fig. 72c) as a pinhole camera would show, is what we would see on a curved surface. The question that arises is exactly how this image is 'processed' by the eye-brain connections, and what effects 'illusions' play.

¹Levy, G.R. "The Greek Discovery of Perspective: Its Influence on Renaissance and Modern Art", JRIBA, Jan.1943, p.56.

²Levy, "The Greek Discovery...", p.52; Hauck, G., Die Subjektive Perspektive und die horizontalen Curvaturen des dorischen Styls, Konrad Wittwer, Stuttgart, 1879, plates 2,3.

There are psychological as well as physiological reasons for seeing straight lines as curves. We can not say how much the Greeks knew about such matters, but we do know that Vitruvius saw the sole aim of refinements as correcting optical illusions. In the case of the horizontal curvature it was to counter a 'dishing' effect. Modern experts seem to agree with him.¹ Luckiesh says that a flat surface would appear slightly concave unless it was raised in the middle.² Dinsmoor adds the columns as a contributing factor because the long row of vertical columns bearing down upon the horizontal line of the platform would presumably increase the illusion. It is now an accepted fact that the mere act of raising the head (or lowering it) can cause 'distortions' or illusions.³

A sort of which-came-first, the-chicken-or-the-egg, argument exists concerning horizontal or upward curvature. It is generally found in both foundation-stylobate and in the entablature.⁴ Vitruvius favors the foundation as the original curved surface and Dinsmoor agrees.⁵ The

¹Lawrence, p.172; Dinsmoor, AAG, pp.164,166.

²Luckiesh, p.196.

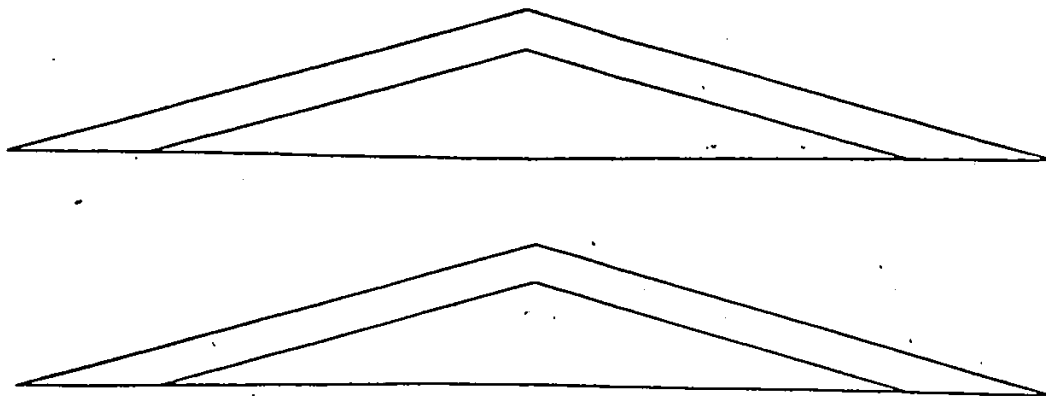
³Kaufman, L. & Rock, I, p.120.

⁴An exception is the Propylaea where the entablature is curved, but - probably because of the steps - the stylobate and foundation are not curved.

⁵Dinsmoor, p.167, fn.2.

arguments seem to revolve on which architectural element creates the stronger illusion (if one disregards the practical purposes of a curved floor).

Penrose and later Thiersch argued that the lines of the pediment caused an unsightly dip which was obviated by a rising curve as in the diagram below:



Drawings to illustrate the Penrose Theory of the Gable Correction.

The line under the upper gable appears to sag downward and is really straight. The line under the lower gable is curved upward to correct the illusion, and appears to be straight. From Thiersch.

Fig. 73. reproduced from Goodyear, p.60.

Ictinus, according to Penrose, never thought to make his columns of unequal length, and so his entablature curve was transferred to the foundation. Lawrence seems to agree when he suggests that "it is conceivable that the idea began in domestic buildings when the wooden architraves were propped so that they rose convexly to prevent sagging".¹ On the other hand Vitruvius, our earliest authority, in

¹Lawrence, p. 175. But Lawrence also mentions that the domed floor curve was carried up to the entire height of the building. (p.174.)

describing how to set a floor told how to set it at its 'right inclination'.¹ This presupposes a practical purpose, and perhaps a curved floor, which would, even in a domestic situation have imparted its curve to the upper elements.

The actual purpose of the curvature can perhaps be traced back two decades from its first tentative appearance in Corinth's Temple of Apollo² to the Croesus Temple at Ephesus (c. 560 B.C.). Here the pavement sloped up towards the cella giving a deck roof effect.³ It must have been intended to facilitate run-off of rainwater. If it also corrected a disagreeable illusion then so much the better.

The reasons for imparting a curve to a raking cornice can have little to do with rain. Illusions must have played a role, or perhaps it was just that the architect, having imparted curvature to the architrave, simply wanted to be 'consistent' or canonical.

A further reason for horizontal curvature is said to be a sort of empathy for the very slight curvature of the horizon. For the Greeks this may well have been a factor, for they did love the sea. But if the Egyptians did influence the Greeks, then what inspired them? Certainly not the sea, or the shape of the pediment.

¹Vitruvius, VII, I, 4.

²It's use is so subtle on the flank that it is often reported to be present only on the front. (Dinsmoor, AAG, p.90)

³Dinsmoor, AAG, p.166.

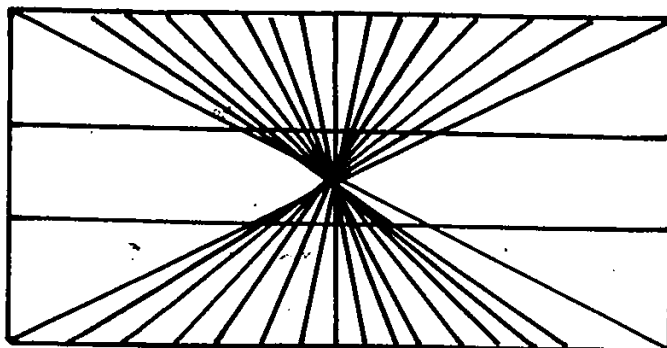


Fig. a. Herring's Illusion.

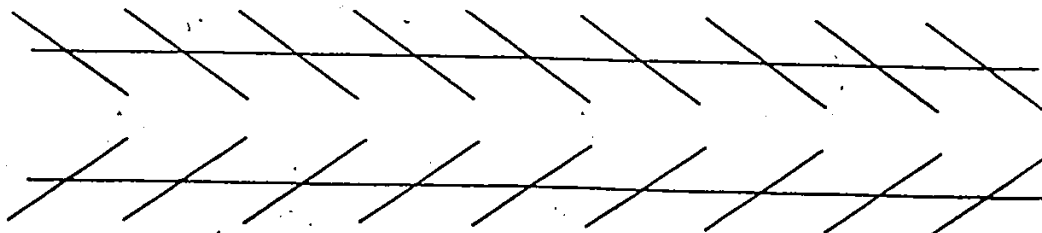


Fig. 37. Optical Illusion of Converging Lines, produced by Acute Angles.

The lines which appear to converge in the direction from right to left are really parallel. From Thiersch.

Fig. b. Reproduced from Goodyear, p.61.

Fig.74.

Both illusions can be used to show why the horizontal lines, especially in the entablature, are curved.

From the optical or illusory we move to consideration of the aesthetic purposes of horizontal curvature. It is axiomatic that all curves convey the feeling of motion while only one of the three straight lines do.¹ Curves impart a feeling of strength, resiliency, vitality. Furthermore, they conduct the eye about the temple and involve not just the 'image' itself in the perception process, but the whole oculomotor apparatus.² Finally, the curve , in the abstract, conveys a gentle but vital movement up, a thrust, as it were, against any downward pressure.³

The diagram on the next page suggests that the taper of the columns is a factor closely allied with horizontal curvature. It is a corollary that entasis should be closely associated with both. Columns with and without taper are shown first in normal rectilinear situations (1), then with curved stylobates and entablatures with no compensation in column lean (2), then with vertical columns (3), and finally with inward leaning columns, as in the Parthenon.

¹Vertical and horizontal lines are static; the oblique line conveys movement.

²Johansson, Gunnar, "Visual Motion Perception", Scientific American, June, 1975, p.78.

³Collier, Graham, explains the theory of forces or movement (thrusts, centripetal, inert) in Form, Space, and Vision, Prentice Hall, Englewood Cliffs, 1963, pp. 129-144.

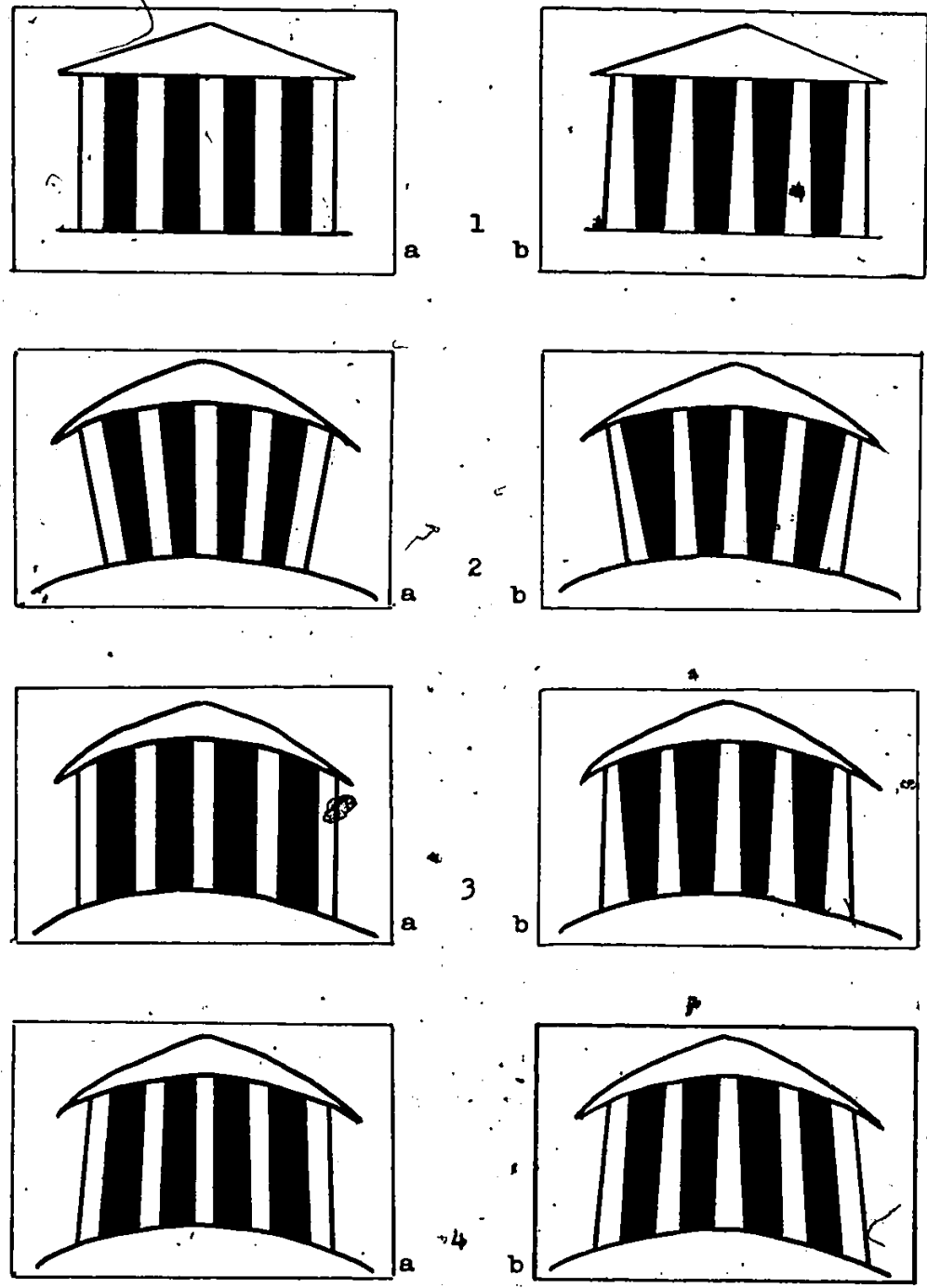


Fig. 75. Taper and horizontal curvature; their apparent interrelationship

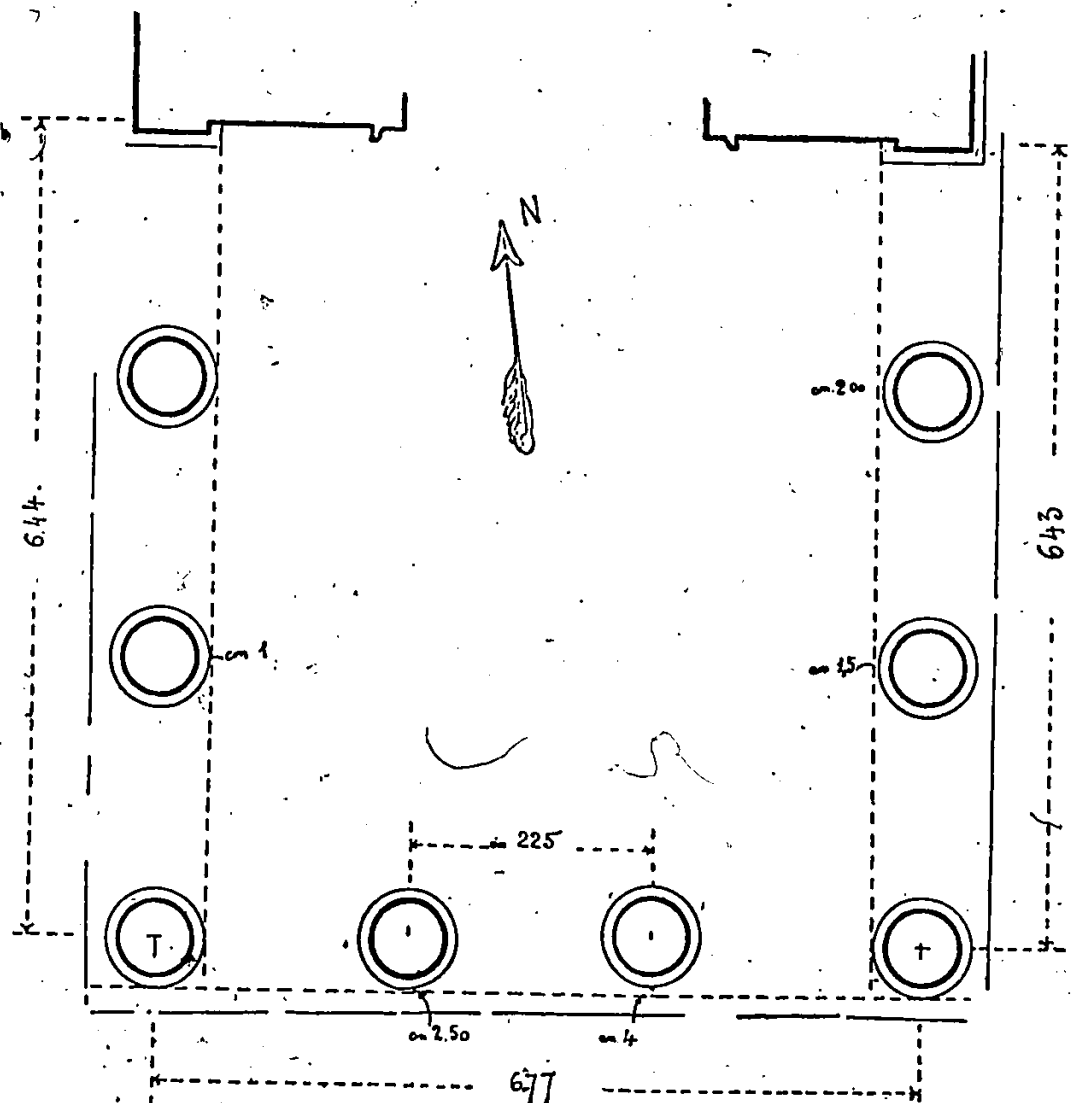


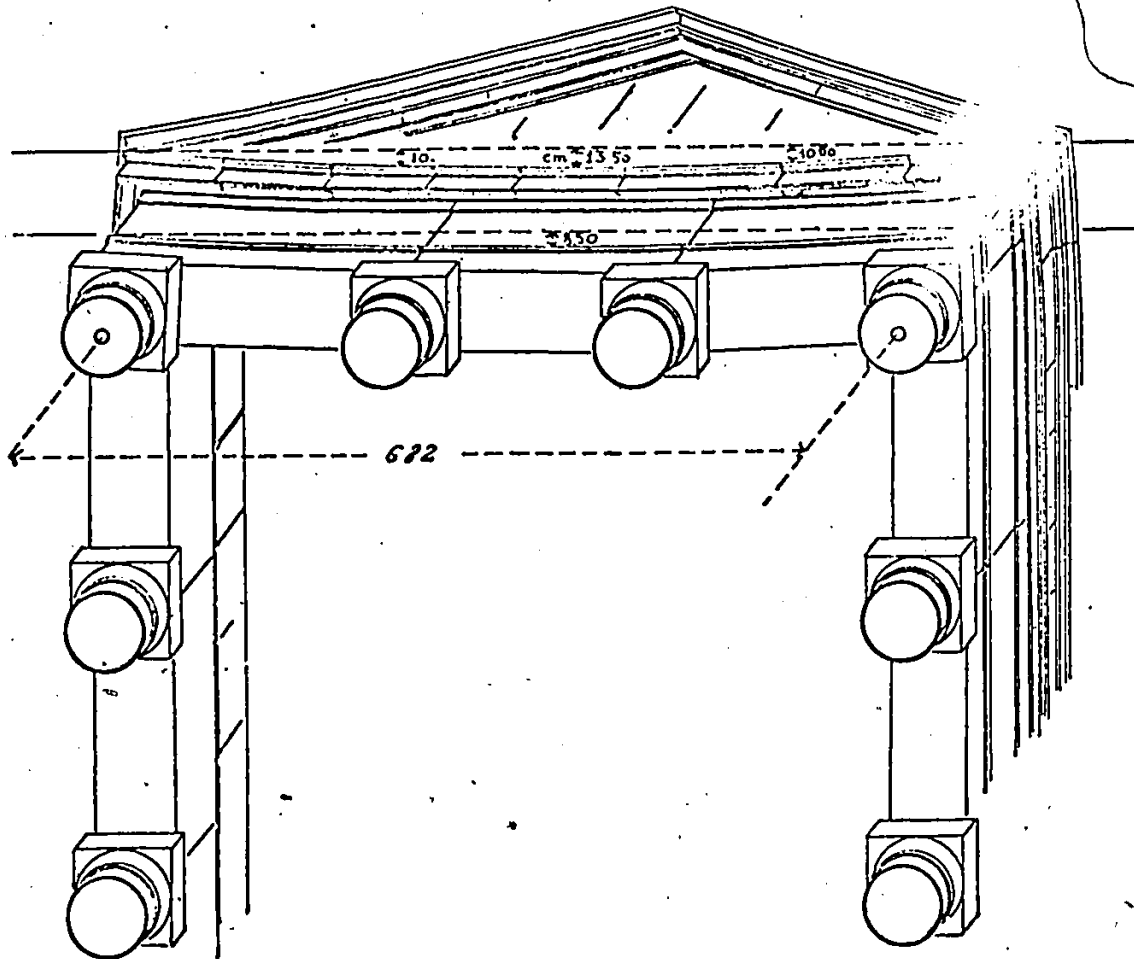
Fig. 76.

Ground-plan of the Temple of Hercules at Cori.

Showing the concave curvature as beginning in the bases of the columns. Reproduced from the "Mittheilungen des K. D. Archäologischen Instituts," by courtesy of Professor Gustavo Giovannoni.

(Reproduced from Goodyear, Greek Refinements, p. 51.)

This page and the next two will show that the practice of imparting some sort of horizontal curvature was used at times by the Romans.



Drawing of the Concave Curves at Cori, as seen looking up; with Surveyor's Measurements.

Fig. 77 Published by courtesy of Professor Gustavo Giovannoni. From the "Mittheilungen des K. D. Archäologischen Instituts."

(Reproduced from Goodyear, Greek Refinements, p.48.)

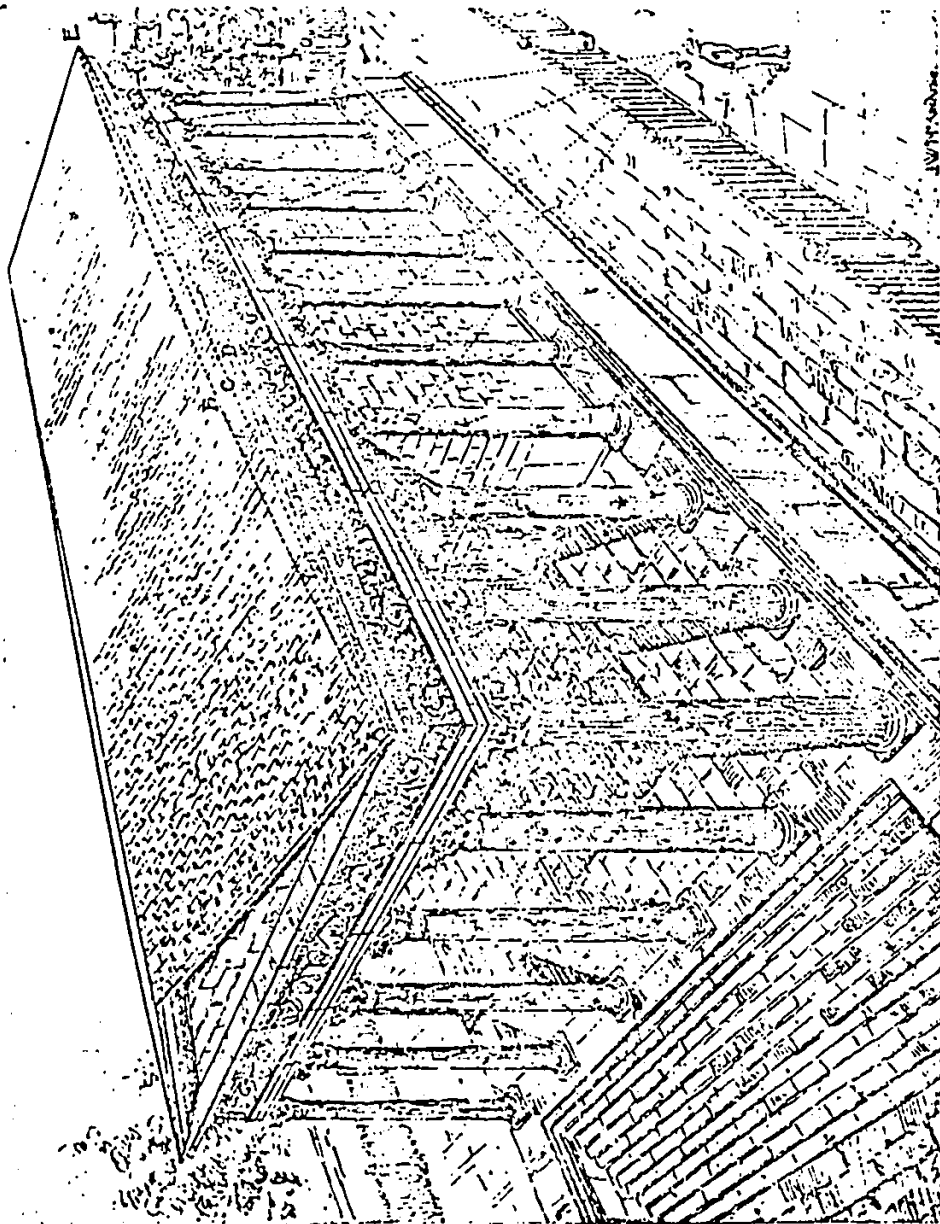


Fig. 78.

Bird's-eye View of the Maison Carrée at Nîmes. West Side.
 The curving dotted line illustrates the optical effect of the curve in plan as being that of a curve in elevation. See Appendix.
 Curve in plan - the entasis principle as used in the Roman provinces.
 (reproduction from Goodyear, Greek Refinements, p.45.)

2. Degree of curvature

Degree of curvature is generally expressed in terms of maximum variance from an imaginary straight line from edge to edge. It is also expressed in terms of arcs or circles or conic figures of a stated radius or diameter. Sometimes it is stated in terms of ratio to some length or 'module' in the building. It might be expressed in terms of a unit of measurement (Greek, metric or British) or even related somehow to geographic terms, especially degrees of latitude. Recently metrologists and archaeo-astronomers have related it to the speed of light or the circumference of the equator, etc. It follows that the reader is often in a quandary about what is implied.

Dinsmoor gives the Parthenon's flank upward curvature at $4 \frac{5}{16}$ inches, or the curve of a large circle with a $3\frac{1}{2}$ mile radius. The flank of the Older Parthenon was given a gentler $2 \frac{3}{8}$ " rise with a projected circle of $7\frac{1}{2}$ miles. Then Dinsmoor warns:

But it is not to be supposed that the architect ever troubled to calculate the radius or to establish the form of an arc of such a theoretical circle.¹

Rather, the Greek builder worked out a system that was simple and pragmatic and produced the necessary curves of awesome dimensions - if one chose to project them. It is by such gestures that some writers today attempt to dazzle us. Our concern should be with the system used by the Greeks.

¹Dinsmoor, AAG, 166.

3. Nature of Curvature

It is generally conceded that the curve was parabolic. This unanimity is perhaps the result of the tacit acceptance of a modus operandi such as is suggested by Dinsmoor, or Burnouf, or others, wherein there is a progressive drop-off from center. Stevens argues in favor of the parabola.¹ Penrose declares outright that the Parthenon curve is parabolic,² and while Dinsmoor uses the Parthenon's 'parabolic' dimensions in illustrating the use of scamilli impares, he also adds "at this tremendous scale the resulting parabolic construction would be indistinguishable from a true circular arc."³

Dinsmoor's version of the scamilli impares process is illustrated on page 155 with the intent of illustrating how closely the process resembles the entasis technique. It should be noted that the scamilli impares would automatically impart a parabolic curve. Stevens' argument is convincingly made and includes reasons for the curves' irregularities, among them, the fact that Ictinus' drawing for the curve could only approach mathematical accuracy and the fact that there were opportunities for error in execution.⁴

¹Stevens, Hesperia 12, 1943, pp. 135-143.

²Penrose, p.30.

³Dinsmoor, AAG, pp.166-8.

⁴Stevens, G.P., "The Curve on the North Stylobate of the Parthenon, Hesperia, 12, 1943, p.136.

4. Random Notes on Upward Curvature in Certain Temples

Croesus Temple at Ephesus: Pavement slopes down from the cella, probably to shed rain. (Dinsmoor, AAG, p.166.)

Temple of Apollo at Corinth: Though it did not have entasis it introduced for the first time the optical refinement of upward curvature in the stylobate of both front and flank (Dinsmoor, AAG, pp.90,166). Penrose (p.104) thought the curvature was limited to the front. Others have ascribed the curvature to 'settlement at the corners' but they have been effectively disproved, (Dinsmoor, AAG, p.166.) because the foundation is on solid rock. Probably the first invention of conic curves occurred here and at early Athens.

Peisistratid Temple of Athena: It had a curved stylobate of Kara limestone and introduced the refinements of upward curvature and column inclinations to Attica. (Dinsmoor, AAG, pp.90, 150, 166)

The Older Parthenon: It also helped introduce conic curves in the foundation. The planned rise on the flanks was $2 \frac{3}{8}$ inches which would give a projected circle of $7 \frac{1}{2}$ miles radius. The curve on the south flank was intensified to accommodate the new Parthenon which was actually countersunk in the top of the old Parthenon platform. The NE quarter was on solid rock and helps disprove the 'corner settlement' theory. (Dinsmoor, AAG, p.166)

Parthenon: The curved foundation rises $2 \frac{3}{8}$ " on facades and $4 \frac{5}{16}$ " on flanks. The arc on this last flank would form a circle $3 \frac{1}{2}$ miles in radius. The temple may have been realigned when enlarged to re-orient it with the sunrise which would account for the top of the curve being off center. (Dinsmoor, AAG, p.166)

Theseum at Athens: Like the Parthenon it has curvature on both entablature and stereobate. The curves are nearly parallel. Front curvature is a rare unit measure: one dactyl or $1/700$ of the breadth of the front. The flank is .105 or $1/1000$ part of the length. The increment in the entablature is about one-fourth part less than in the stylobate in the front and one-tenth part less in the flanks. (Penrose, Ch. X; Dinsmoor, AAG, p.166) The actual rise is $3/4$ " on the facades and $1 \frac{1}{4}$ " on the sides.

Propylaea: The stylobate is level to accommodate the stairs which are some 12 feet wide, but the central columns were made higher so that there could be a $3/4$ " rise to the architrave. This curve is carried to the raking cornices. Dinsmoor and Penrose use these facts to 'prove' their different theories on where curvature started.

Temple of Apollo at Didyma: This temple near Miletus has a $2 \frac{3}{8}$ " façade curvature. (Dinsmoor, AAG, p.230)

Ionic Temple at Pergamum (on the theatre terrace) was rebuilt by Caracalla. It has upward curvature. (Dinsmoor, AAG, p.273)

Argive Heraion: has curvature

Unfinished Doric Temple at Segesta: This temple has a distinct curvature. (Dinsmoor, AAG, p.166)

The following do not have upward curvature

Hera Lacinia (Acragas): The illusion sometimes seen is presumably caused by the camera lens. (Dinsmoor, AAG, p.110).

Bassae: (Dinsmoor, AAG, p. 155)

Temple of Athena Nike: (Dinsmoor, AAG, p. 168)

Propylaea platform and stairs: (Dinsmoor, p.167)

Temple of Zeus at Olympia, (James, E.O., From Cave to Cathedral, Praeger, New York, 1965, p.266)

smaller Periclean temples: (Dinsmoor, AAG, p.166)

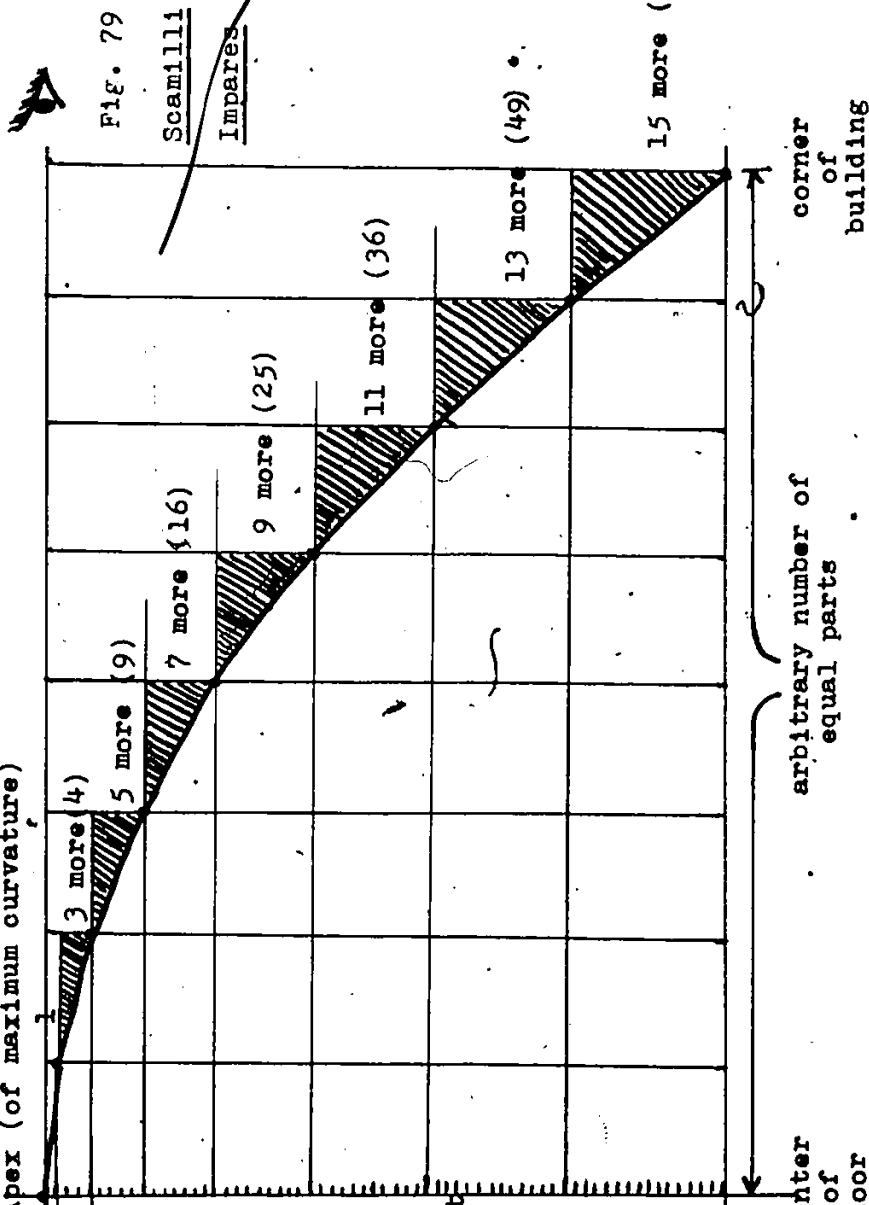
DINSMOOR'S DIAGRAM FOR CONSTRUCTION OF STYLOBATE CURVATURE (Modified)

Horizontal line

Apex (of maximum curvature)

Procedure:

- 1-decide maximum increment;
- 2-divide middle to corner distance of floor-into arbitrary number of equal parts (8 here);
- 3-divide maximum increment (4" here for convenience) by the square of the number of parts (in 2);
- 4-this gives size of fractional parts of height
- 5-a horizontal at 1 unit will determine the location of the first ordinate when it hits the first vertical. (1 x 1 = 1);
- 6-2 x 2 = 4, so count down 4 units from the very top (or 3 more after the first ordinate) to



- locate the ordinate for part 2;
- 7-3 x 3 = 9..so establish this ordinate at the ninth unit or 5 units below the above..
- 8-proceed as above to finish arc;
- 9-determine corresponding points on opposite side to complete curve;
- 10-the actual ordinates in terms of units can be determined on a piece of paper (or on the ground)

or
11-scamilli impares (levelling blocks) can be used in actual construction.

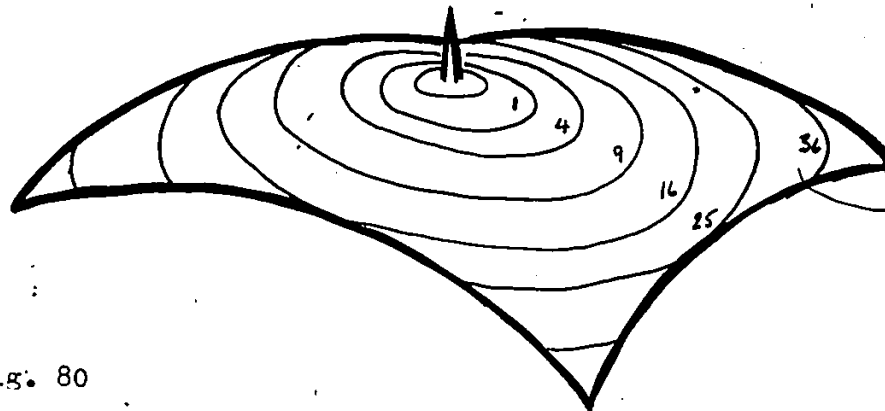


Fig. 80

Applying Upward Curvature (Hypothetical Method by author)
Scamilli impares are placed on the radiating circles which might be determined using Dinsmoor's method, or others'.

- 12- Note especially that the increase is constant and can be determined for any point however far from center.
- 13- Note too, that in determining the maximum increment from the middle to corner there will naturally be a greater curve to the flank than to the facade.

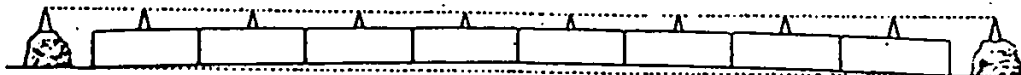


Fig. 81. The Greek Method of Constructing Horizontal Curves by Scamilli Impares, as interpreted by Burnouf.
From the "Revue Générale de l'Architecture" for 1875.

Fig. 81 Burnouf's scamilli impares.

The Dinsmoor system may sound difficult, but given the right progression of numbers, eg, 1, 4, 9, 16 etc, to arrive at depth from center, one could easily use a rope anchored at temple center and apply the right number of units or Burnouf's 'little stool' to impart curvature. (Fig.80)

Summary

If we knew more about scamilli impares, what they were, and how they were used, we might know more about the horizontal curve. This much we can say:

- a. the curvature might be only at front and back;
- b. it might be at front and back and flanks;
- c. curves are generally higher above the horizontal on the flanks than on the front and back;
- d. often there is not so much a curve per se as a series of chords whose joints correspond (however roughly) to the coordinates on a curve, as in Penrose's diagrams of the Parthenon and Hephaestum;
- e. the curvature seems to serve an architectonic function, if only because it occurs at its maximum precisely where there is the greatest weight (in mid-pediment);
- f. the curvature starts in the foundation because the steps had to be of equal height from end to end;
- g. since columns were normally of equal height the curvature was extended to the entablature, even to the raking cornice; (Penrose contests this theory in arguing that curvature in the entablature came first.);
- h. there is a famous exception to the above in the Propylaea which has a level stylobate and stairs under a curved entablature;
- i. the entablature is sometimes not curved as much as the stylobate;
- j. the function seems to have been illusionist, aesthetic and practical.

GREEK ARCHITECTURE

OPTICAL CORRECTIONS IN ARCHITECTURE

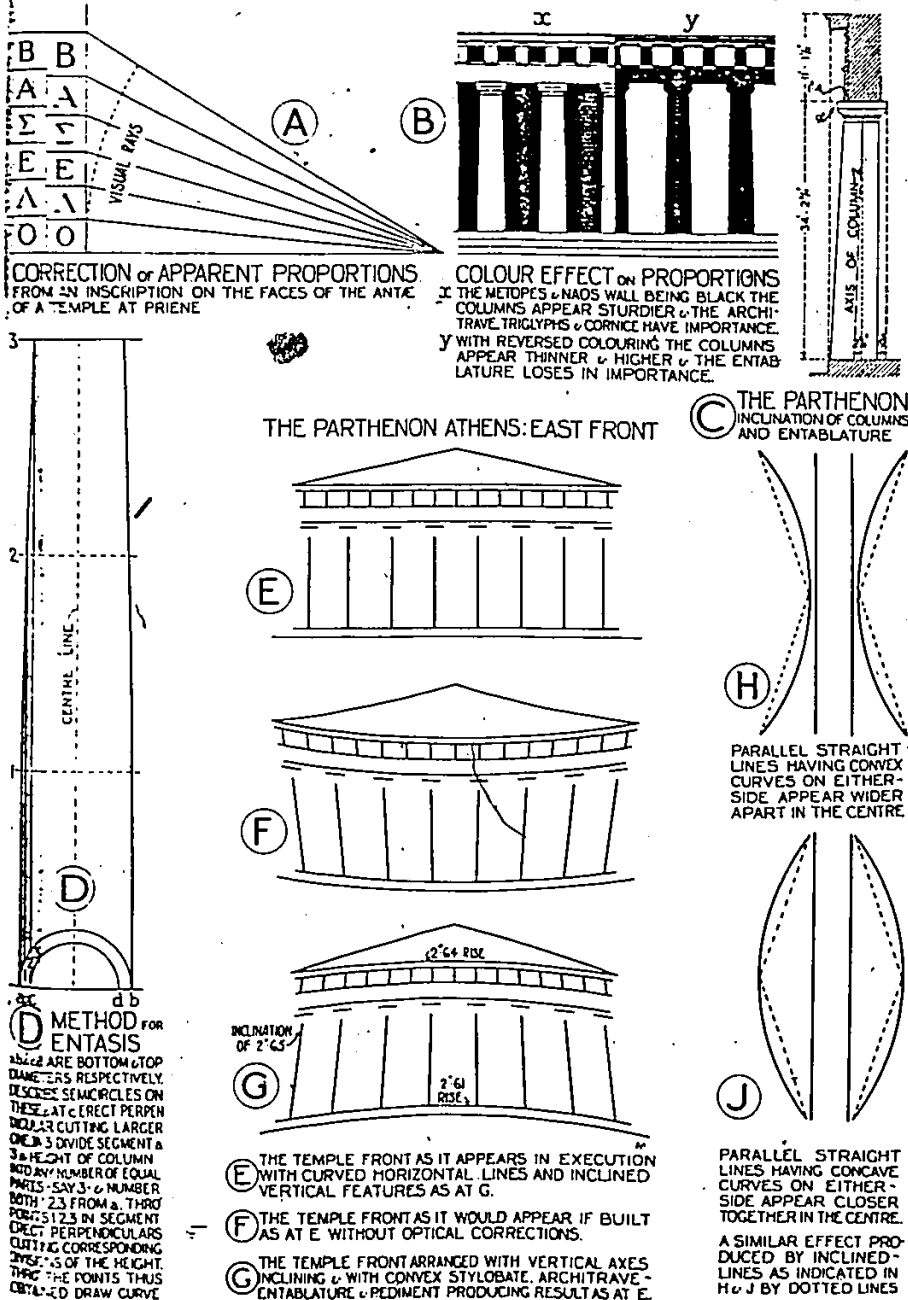


Fig. 82. (Reproduced from Fletcher, Bannister, *A History of Architecture on the Comparative Method*, University of London, London, 1961, p.95.)

Other Refinements

Inclination

The various options open to an architect who puts a tapered column on a curved stylobate are illustrated on page 147. The Greeks chose to lean their columns inward on flanks, facades and corners so that a projection of the columns might produce a pyramidal form, the quintessence of stability.¹ (Fig. 83)

The principle of inclination imparted to the whole derives from the same architectural principle that demands taper, that is, that the chief strength must be at the place of the origin of stress. There are other ramifications: unless the columns are so inclined the upper intercolumniations are greater at the top than at the base and the columns seem to fan out as in Figures 1, 2, 3 on page 147. There are even



Fig. 83

¹Lawrence goes so far as to say that inclination was a normal practice, (p.170), in which case, it can hardly be termed a 'refinement'. The pyramid so formed by the inclination of columns in the Parthenon has its apex 5, 856 feet above the pavement. (Penrose, p.36).

aesthetic principles at work, for the negative areas between columns (as in Fig. B, p.158 and in 1, 2 and 3 on page 147) constitute very strong downward thrusts in the column arrangements which are not tapered, too strong to create the tension of upward and downward elements that was apparently so desired. Finally, there might have been historical and technical reasons for inclining the columns. Some see the Doric temple's origins in ancient table-like altars and canopies whose baldachino structure would be stronger if the four supporting corner columns were slanted inward. We have it from Vitruvius that 'vertical' elements should be slanted to correct optical illusions:

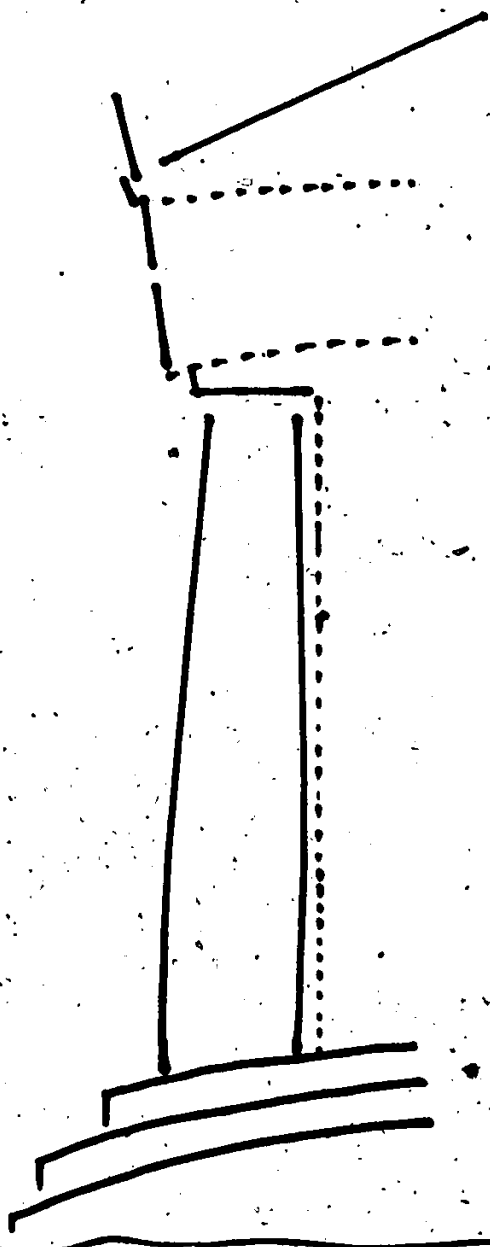
All the members which are to be above the capitals of the columns, that is, architraves, friezes, coronae, tympana, gables, and acroteria, should be inclined to the front a twelfth part of their own height, for the reason that when we stand in front of them, if two lines are drawn from the eye, one reaching to the bottom of the building and the other to the top, that which reaches to the top will be longer. Hence, as the line of sight to the upper part is longer, it makes that part look as if it were leaning back. But when the members are inclined to the front, as described above, they will seem to the beholder to be plumb and perpendicular.¹

Unfortunately, as elsewhere, his Ionic (?) criteria are not the same as those employed in the Doric by fifth century Greeks - neither in the amount of inclination nor in the direction involved. This can best be illustrated by Fig. 84.

¹Vitruvius, III, V, 13.

VITRUVIAN INCLINATIONS

(one twelfth part of the tilted part's height)



acroteria
antifixae

gables,
tympana
coronae

friezes

architrave

abacus

column

stylobate

PARTHENON INCLINATIONS

(if there is a pattern it is not obvious.)

1 in 100
(1/20 ht)

1 in 100

1 in 80

1 in 100

Parthenon,
Propylaea,
Theseum,
Erechtheum,
all have
inward column
slant.

1 in 150
or
1/3 of semi-
diminution
or
5X entasis

cella wall
batter is
1 in 80

1 in 250

western faces of
antae lean forward 1 in 80
(so that capitals overhang
bases.)

Fig. 84 Comparison and contrast of inclinations

The diagram illustrates that the Greeks tilted forward only very minor elements and they tilted back - as they did the columns - those larger elements that performed a more structural role. Those few parts that do tilt forward are rather like punctuation in the rhythm of the side or facade, and they occur only at points of tension between strong 'horizontal' or raking and oblique elements and so serve to smooth out the transition (e.g. from column to architrave) or to draw attention to it (as in the case of the roof edge).

Penrose draws attention to the simple relationship between qualities of like nature: the columns in the Parthenon leaned .228 of the whole height of the column (namely 34.26) - a multiple of column and inclination of exactly 1 in 150 and proportional to the semi-diminution and entasis (one-third of the first and five times the other). It was also identical with the increment of curvature in the fronts, so that we can reduce the semi-diminution, increment, inclination and entasis to a 12 - 4 - 4 - 3 relationship.¹ The cella walls also incline, but not the transverse wall which contains the door. The tympanum, logically enough, leans backwards 1 in 100. But the antae lean forward.²

¹Penrose, p.36.

²Compare these last two with *Basilica at Paestum*, where the antae lean inwards (MacKendrick, *The Greek Stones Speak*, p.256) And with the Ionic and Vitruvian forward tilt of the entablature. (Cook, R.M., *Greek Art*, p. 227.)

Sculptural elements are said to have been tilted forward, though one wonders if the sculptor himself might not have been asked to compensate for the acute viewing angle. The forward tilt suggests that the guiding hand of the builder ensured that every part was accorded the proper treatment.

One is tempted to wonder exactly how much the Greeks knew about the physiological theories that explain illusions that occur above the normal fixation level of the eyes.¹

Other refinements

Consideration of most other refinements in the Doric Greek temple results in the same quandary: it is virtually impossible to say precisely why the deviation was devised and what other significance was attached to it in time. Intercolumniation was varied; for instance, for many reasons. Poor workmanship might have been a factor at some time. It might also have come about as a result of the habit of replacing old (wooden) columns with newer ones of different proportions and styles. The problem of centering the new column could easily have led to an appreciation of the optical effect of irregular intercolumniation. There is the Greek abhorrence of pure

¹Ptolemy presumably was concerned with the moon illusion which modern scientists sometimes ascribe to compensatory or counter rotation theories. Plato, as we have seen elsewhere in his sophist dialogue refers to the effects of perspective and the need to exaggerate height (which a forward tilt actually does). Psychologists have also shown that this illusion is found operating in lower animals than man.

symmetry and the effect of a canon that would produce a more 'organic symmetry'. Perspective views of apsidal colonnades might have suggested bringing the columns closer together at the edges; so might vase depiction of temples. There is no doubt that the problem of dealing with the triglyph canon was a factor. It has been suggested that different work gangs would operate in slightly different ways and so create 'anomalies' in the same building, anomalies that would contribute greatly to the overall impression it conveyed. The Greek propensity to work 'frugally' and with the materials on hand at the site must also be considered.

One should not be so vain as to search for a theory that embraces all cases. It seems that refinements in the Greek temples were applied separately when there seemed to be a want. We have concerned ourselves with those that seem to be related to entasis.

WORK TO BE DONE AND SOME CONCLUSIONS

1. Evidence

The paucity of literary references and the paucity and quality of extant temple remains have necessitated a far ranging approach to the topic. Still, the use and nature of entasis by the Greeks can, perhaps, be better understood in perspective.

Very little evidence remains in stone; what does exist has not really been properly measured. The pertinent information, if it does exist, does not seem to be readily available. Penrose published his findings about one column in the Parthenon. He then determined the nature of the entasis curve and substantiated his hypothesis by measuring another column which was in such poor condition that he had to measure it four times and average his sets of figures. He measured from the interior of the flute because the exterior was in a poor state. His final figures show a greater margin of error than he normally allows himself. He says he further checked his findings by measuring three other columns, but he gives no data and one must assume that the margin of error or deviation from his original figures is even greater, that is, that his proof is less conclusive. And yet, Penrose's is the most complete and reliable data we have.

With modern stereogrammetric techniques, and more especially with the computer and devices like the polariscope, we are in a better position than ever to study entasis and

refinements in an orderly and scientific manner and to arrive at logical and probable conclusions. But, in terms of time, we may have reached the point of no return, because improper restoration and conservation techniques and especially the results of pollution may have so destroyed the evidence that merely getting further accurate information might be impossible.

2. Theories of Perception Reconciled

Damion, Heron, Philo and Vitruvius, as we have already seen, talked of optical illusions and the need to evoke the appearance of reality by means of some deception or compensation. Aristotle, perhaps by chance, referred to the parts of the process of temple building in explaining how wholistic the act of seeing is.¹ Still, we cannot be sure how the Greeks thought the brain perceives and recognizes objects, nor whether (or how) their opinions or knowledge in these matters were factors in using entasis and refinements.

Recent experiments suggest there might not be a Gestalt parallel one-step process in seeing, but a step-by-step process which more closely parallels what the Greeks must have felt about the vagaries of vision! It remains for someone with expertise in classics, psychology, optics and the neural process to bring all pertinent data together and arrive at conclusions.

Meanwhile, let us observe that the memory system of the brain must contain an internal representation of the object it recognizes. This image is in the form of neural activity and quite unlike the retinal image of the object. When one looks at an object one's eyes scan

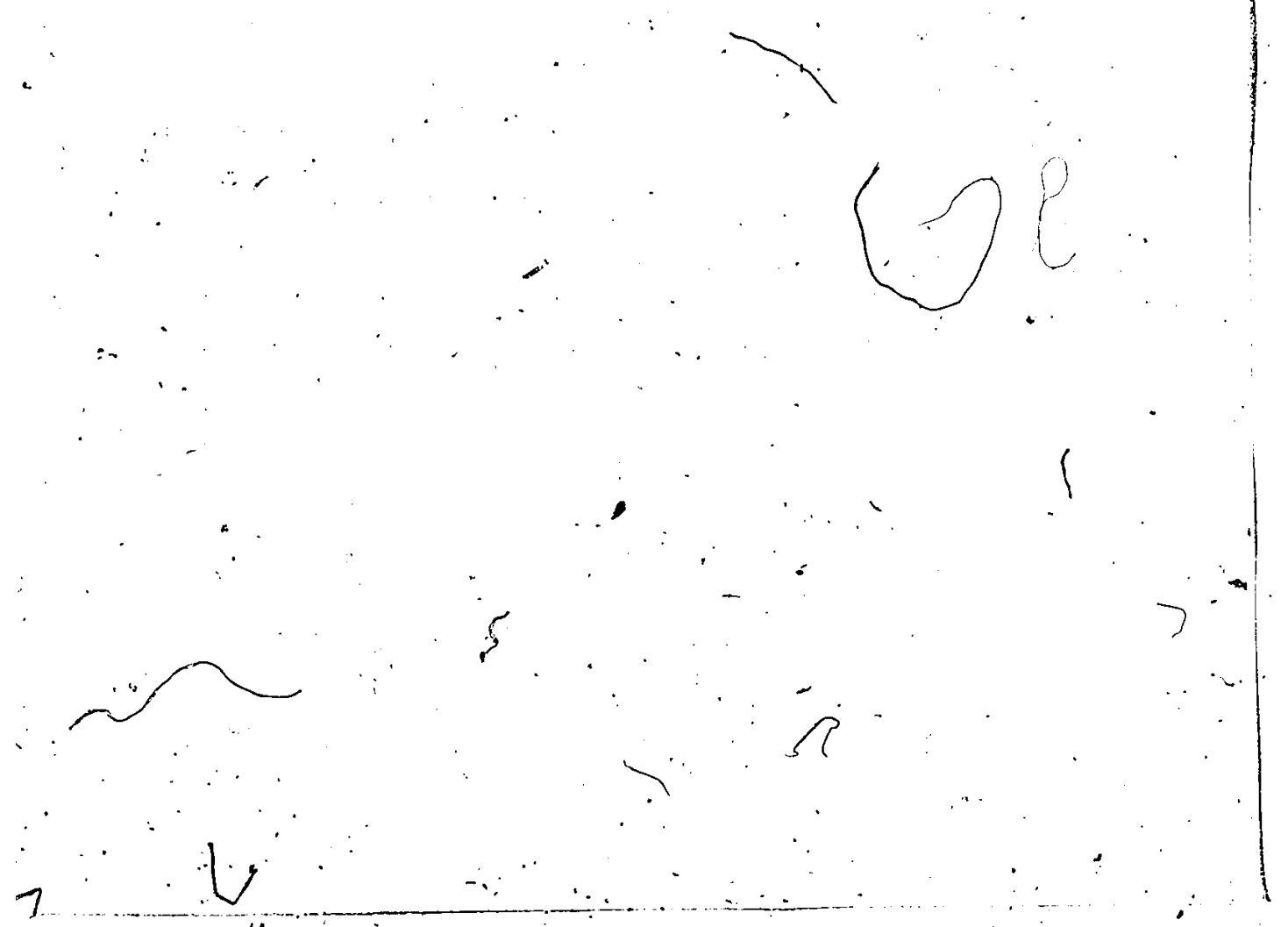
¹Aristotle, Ethics, X, iv.

the object. Scientists can now measure the path the eye moves in and also time the saccades or rapid eye movements between fixations.¹ The scientists have not (to my knowledge) studied what happened when someone looked at a Greek temple with refinements. They have ascertained, however, that fixations tend to cluster around the angles and on unpredictable contours in the object seen. They propose, as a result of their studies, that in the internal representation or memory of an object main characteristics are linked together in a 'feature ring' sequence by the memory of the eye movement required to look from one feature to another. This is generally done in a fixed order. The scanning process when the object is familiar will take as long as 35% of the viewing time - much longer than when the object is rejected because it is unfamiliar. Internal shifts of attention accompany the eye movements and these tend to vary from subject to subject, because we all learn to see an object in a different way.

Artists have for centuries tried to control this scanning path, in architecture, no less than in painting and sculpture. Until we know more about what Ictinus wrote, however, we can only speculate that perhaps he was aware of the limited angle of focus of the fovea (one to two degrees) and the fact that this necessitated eye movements in the process of perceiving something

¹Noton, D., and Stark, L, "Eye Movements and Visual Perception", Scientific American, June, 1971, pp. 35-43.

large. That he might have used subtle embellishments - refinements - here and there to increase scanning time and perhaps aid in the act of 'seeing' his temple, is a concept entirely in keeping with the spirit of the Periclean age. One is even tempted to see an analogy between this new concept of seeing 'reality' and the Platonic theory of Ideals.



3. Photography and the Study of Entasis

Photography was used a great deal in the study of entasis and curvature refinements in the last century and into the 1920's. Goodyear used it and perhaps he was discredited because he based many decisions on entasis and refinements on photographic proof alone. Still, the art and science of photography can be used today to tell us more about Greek buildings.

"A photograph represents the retinal image, not how the scene appears."¹ "We do not see our retinal images; and we do not see the world according to the size or shapes of the retinal images."² We do, in fact, tend to see things in terms of their actual size and we draw on our knowledge of context for clues in order to make this determination.³ Cameras render flat geometric photographs that deny our eyes the muscular hints they would get in focusing at near or far objects in reality. Even stereo photography can distort the image we see.⁴ The psychological and physiological experience of looking at a photograph is simply not the same as looking at reality. Still, given certain information, we can learn to 'see' and to be aware of the limitations of what we see in a photograph.

¹R.L. Gregory in Eye and Brain: The Psychology of Seeing, quoted by Dechert, Peter, "Communication, Photography, and the Archaeologist", Photography in Archaeological Research, Harp, E., ed., University of New Mexico, Albuquerque, 1977, p.355.

²_____, p.355

³Dechert, p. 355

⁴Dechert, p. 356

There is no indication that Goodyear ever had the technical data one would think necessary to make sound judgments from photographic proof alone. Nor is this data generally published alongside architectural or archaeological photos.¹

On this subject of 'seeing' it should be noted that the lens, contrary to popular belief, does distort renditions of the original subject because the light must first pass through glass before reaching the film and distortion results because of refraction effects. Only one type of camera offers no refraction - simply because it has no lens. This same camera offers infinite depth of field and focus everywhere. The camera has been used in the space program, in holography experiments and in special multiple exposure flash combinations to photograph the inside of the stomach. It is the only camera that offers an accurate representation of the subject according to the laws of linear perspective. And it can be made for a few cents: the pinhole camera.

Some useful and interesting work could be done by an enterprising photographer who compiled a series of studies of various temples from all angles, with conventional no-shift lens cameras, with adjustable controls on 'studio cameras', and with pinhole cameras - if he recorded all data.

¹The data required would be: camera and lens specifications, format, film and chemistry used, exposure and filter details, range, height of object (if known and in the absence of scale indicators) and distortion adjustments.

4. Illusions and Perspective

The exact nature of illusions used in Greek temples has been difficult to assess, partly because some fit more than one category.¹ Then too, the change we call an illusion might not be optical, but psychological or physiological. Certain illusions have been related to time, geographic considerations, race, nationality, age, sex and learning, as well as visual-motor experience. The ancient Greek temple was very geometric in its proportions; it was on this geometric form that refinements were lavished. It was perhaps an ideal form on which to experiment with illusions. Recent studies show that

the geometry of the decoding of visual stimuli is a relational one similar to projective geometry. In accordance with this geometry, series of relative invariances, or perspective transformations, are abstracted from the optical flow. This results in hierarchical systems of different components that are perceived both in common and in relative perspective transformations. . . . human beings tend to perceive objects as possessing constant Euclidean shapes in rigid motion in a three-dimensional world. In real life these principles of visual analysis taken together give rise to a satisfactorily close correspondence between the physical world and what we perceive that world to be.²

¹The categories and their characteristics are: height and width: vertical segments usually seem longer than horizontal segments of the same length; interrupted extenders: parts of a figure separated by a vacant area appear out of position; contour: open figures appear to have a greater area than closed figures of the same size; equivocal: two or more interpretations are found in the same image; perspective: depth causes equal objects to appear unequal; contrast: combinations and positions cause equals to seem unequal and straight lines curved and color contrasts cause spots or confuse directions.

²Johansson, Gunnar, "Visual Motion Perception", Scientific American, June, 1975, p.88.

The study of perspective, whether it was linear or spherical, was started by Anaxagoras who wrote a commentary (now lost) on his stage backdrop. Richter makes the interesting observation that the Greeks did not invent single point vanishing perspective perhaps because they were stimulated by scene painting, and it was impossible in a theatre, where every person in the audience furnished a different line of sight, to provide a picture that could be unified by a single vanishing point.¹ That the Greeks were stimulated is proven by the great strides made in conveying a third dimension on their vases.² It is interesting to note that these same vases would provide the artist no easy ground on which to paint 'straight' lines, which would, however rendered, curve this way or that depending on how the vase was held or viewed. It is probable that something of this multi-faceted approach was the reason why the Greeks used refinements in such a variety of ways. The building, which they viewed as plastic form, was not, after all to be viewed from a single spot, but from many vantage points.

¹ Richter, G.M.A., "Perspective, Ancient, Medieval and Renaissance", Scritti in Onore di Bartolomeo Nogara, Vatican, 1937, p.386.

² Unfortunately, they showed little respect for the medium and imparted a depth that some consider undesirable.

5. The Polariscope and Structural Analysis.

Several refinements can be said to play functional roles: entasis does make the column stronger and inclination of columns does impart strength. The questions that arise are: by how much? and, is the strength imparted significant? Studies have been made on Gothic structures by making transparent scale models and subjecting them to various stresses in a polariscope. The principle is illustrated below.¹

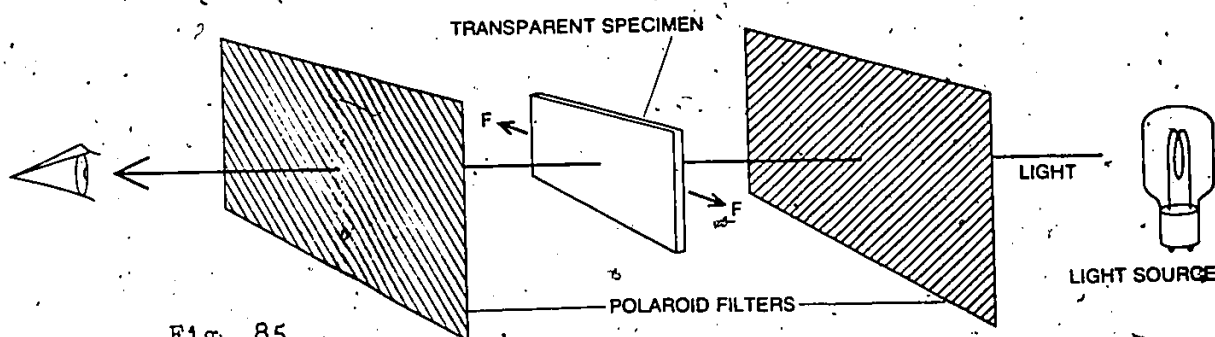


Fig. 85

PHOTOELASTIC PRINCIPLE underlying stress analysis is illustrated. Crossed-axis polarizing filters cut off the light. An unstressed transparent specimen has no effect on the polarization and so the field remains dark, but when forces (F) are applied, the specimen

is deformed. As a result the polarization of light leaving the specimen is altered depending on the magnitude of the forces, the material and geometry of the specimen and the wavelength of the light. This altered polarization is seen as an interference pattern.

Any architecture, Greek included, can only be misinterpreted if its technical aspects are not well understood. When someone does such optical stress analysis of the Greek Doric temple we will be in a better position to relate the aesthetic and illusionistic achievement to the structural imperatives.

¹ Mark, Robert, "The Structural Analysis of Gothic Cathedrals", *Scientific American*, Nov., 1972, p.96. The illusionist argument for changing the pinnacles atop the outer edges of Bourges Cathedral to the center was disposed of when the polariscope showed that the edge pinnacles maintained the integrity of the buttresses by overcoming local tension. (pp.90-92).

6. Theories about Entasis and Refinements Classified

However and why the delicate curves and 'niceties' were put into Periclean buildings, and the Parthenon in particular, there is no denying that they impart vitality and an organic aspect that contributes to the appearance of greater strength and plasticity. The great expense and trouble in introducing refinements shows that they were intended to serve a purpose. (Who could possibly believe that they were merely a show of Attic perversity?) The most ancient sources say that the anomalies were intended to counter optical illusions. It is probable that Ictinus' lost book was a treatise on the subject. In any case, no one has successfully proved that the correction of disagreeable illusions was not a factor.

The peculiarity and subjective nature of most illusions has contributed greatly to the problem of understanding what the Greeks intended to do. Different theories of the causes of even simple optical illusions survive just because the human subject cannot observe and report his own interpretative operations. Illusions also differ depending on time and place, sex and race, training and learning and a host of other conditions. Not everyone will accept any one explanation.

Theories about why the Greeks used entasis and refinements, however, have been classified under three broad headings:

- a. the compensation theory,
- b. the exaggeration theory,
- c. the tension theory.

There is, perhaps, a fourth classification.

The compensation theory

Vitruvius may be said to be responsible for the notion that calculated modulation is designed to counter the deception caused by the eye. He cites raising the center of the floor, thickening the corner columns, curving the stylobate. It matters not that his formulae sometimes do not fit neatly with the Periclean realities. We can expect that the actual recipes might have changed in the five centuries that elapsed since Ictinus built the Parthenon; it is reasonable to assume that the intent of refinements was the same. Besides, Vitruvius had access to Ictinus' book on such compensations or 'alexemata'.

The exaggeration theory

Anti-Vitruvians argue that such lines as are 'wrong' or seem bent were deliberately exaggerated to emphasize some feature of the temple, especially its size. This is especially true of horizontal curvature,

¹Pollitt, J.J., Art and Experience in Classical Greece, Cambridge University Press, Cambridge, 1972, pp.75-78.

entasis and diminution in width of metopes. The main objection to this hypothesis is that 'bigness' does not seem to be a desirable characteristic in Periclean Athens where refinements were used with the greatest success.

The tension theory

This theory has it that the intention of the builder in introducing deviations was to create a tension in the mind of the viewer between what he sees and what he expects to see, so that in struggling to reconcile the two images a fascination grows out of the tension. The mind's neural image presumably expects normal rectilinear exactitude; the eye provides deviations and nuances and the ensuing 'tension' produces a fascination whereby the temple is seen to be vital, organic, ever-interesting. The reality that is known by the mind, the aletheia, is married to the reality known by the senses, the phantasia.¹

τέλος δὲ τῷ ἀρχιτέκτονι τὸ πρὸς
φαντασίαν εὐρυθμίον ποιῆσαι τὸ
ἔργον. καὶ ὅποσον ἐγχωρεῖ πρὸς
τὰς τῆς ὀψέως ἀπάτας ἀλέξήματα
ἀνευρίσκειν οὐ τῆς κατ' ἀληθείαν
ἰσότητος ἢ εὐρυθμίας ἀλλὰ τῆς
πρὸς τὴν ὀψίν στοχαζομένην.²

¹Pollitt, J.J., Art and Experience in Classical Greece, p. 78.

²Helliodori Larissaei Capita Opticorum (as quoted on the title page of Penrose's work.)

the aim of the architect is to make his work harmonize with the demands of the senses and to devise methods for deceiving the eye, as far as possible; his object being (to achieve) not actual, but apparent, symmetry and eurythmy.

Archaeoastronomers may force us to add a fourth classification, because the map-projection theory of Stecchini does not fit easily in the first three categories. We must await publication of the argument in detail.

Meanwhile, the theories mentioned all seem valid. Each contributes a feasible explanation that somehow fits the Greek scheme of things. Nor are the three necessarily mutually exclusive. Entasis and refinements did not mushroom suddenly in one precise place and time. There were probably different reasons for introducing each refinement, reasons prompted by a variety of factors, tastes and whims. For instance, we can say that entasis does impart actual strength to the column, though the amount is minimal. Specialists in optics and illusions do recognize that effects of irradiation, deflection, chiaroscuro and attenuation are indeed countered by the use of entasis. A natural proclivity to use curves because they are more beautiful or animated than straight lines may have been a factor, as might theories of aesthetics relating to the shaft's architectonic role or the imparting of vitality, elasticity and flexibility with grace. A preoccupation with the laws of elementary perspective

seems to have given impetus to the movement about the time the Parthenon was built. Authorities for the above points of view abound.

Such evidence as exists suggests that entasis and refinements were not administered according to strict rules. If they were, we have been singularly unsuccessful in detecting them. Rather there was a subjective or ad hoc approach, and generally speaking, one must subscribe rather more to the tension theory than the others.

When not advised (of it) the spectator feels something unusual; when advised of it he recognizes a delicate attention which delights him...escapes analysis..., but...captivates us even when we are ignorant of its true sense and cause.¹

¹Choisy, pp.408-409.

GIVING THEIR APPROXIMATE DATES AND PRINCIPAL DIMENSIONS AND PROPORTIONS:

- 1 Including for comparison a few other accurately dated buildings, the Athenian Treasury at Delphi, the Propylaea and the Monument of Nicias at Athens, and the Mausoleum at Halicarnassus.
2 Dimensions are normally given to the nearest half-inch in limestone buildings, to the nearest quarter or eighth in marble buildings (for measurements in metres see Appendix).
3 All dates are B.C. unless otherwise stated.
4 In the case of unfinished stylobates, the finished dimensions are given (subtracting protective surfaces).
5 When two dimensions or proportions appear side by side in the same column, the first always refers to the fronts and the second to the flanks; but when variations (other than the contracted corner spacings in Doric buildings) occur within either front or flank, the normal is shown above and the extreme variation below, respectively.

Date	Name of Temple	No. of Columns	Top of Stylobate		Ratio Width to Length	Axial Spacings	Lower Column Diameters	Height of Column	Height of Entablature
			Front	Flank					
	DORIC		ft. in.	ft. in.	3:	ft. in.	ft. in.	ft. in.	ft.
c. 590	Olympia, Heraeum	6 by 16	61 6	164 1	2:667	11 8, 10, 8½	{ 4 2½, 3 3½ 3 11½, 4 1	17 1½	2
c. 565	Syracuse, Apollo	6 .. 17	70 9	181 6½	2:565	{ 12 4½, 10 11 14 7	6 7, 6 0½	26 2	2
c. 555	Syracuse, Olympieum	6 .. 17	73 6	203 7	2:770	13 4½, 12 4	6 6 1	c. 26 3	2
c. 550-530	Selinus, 'C'	6 .. 17	78 6½	209 0½	2:661	14 5, 12 8	6 3, 5 11½	28 4½	14 6
c. 540	Assos, Athena	6 .. 15	46 0½	99 5½	2:160	8 7, 8 0½	3 0	15 8	6
	Corinth, Apollo	6 .. 13	70 6	176 11	2:505	13 2½, 12 3½	5 8½, 5 5	23 9	6
c. 535	Selinus, 'D'	6 .. 13	77 6	182 8	2:367	14 4, 14 9	5 7	27 3	12
c. 530	Paestum, Basilica	9 .. 18	80 5	178 0½	2:214	9 5, 10 2	4 9	21 1½	7
c. 525	Selinus 'FS'	6 .. 14	79 11½	203 9	2:544	14 8, 15 1½	5 10½	29 10½	12 3
529-515	Athens, Athena (Peisistratid)	6 .. 12	69 10½	141 7	2:026	13½, 12 7	c. 5 4, c. 5 1	c. 24 3	11
c. 520-450	Selinus, Apollo ('GT')	8 .. 17	164 3	361 3	2:199	{ 21 5, 21 8 21 8	{ 9 9 10 8½, 9 9	48 2½	21
c. 510-409	Acragas, Zeus Olympius	7 .. 14	171 0½	361 2½	2:088	26 4, 26 10	13 3½	56 8	24
c. 510	Paestum, Demeter	6 .. 13	47 8½	107 10½	2:261	8 7½	4 2	20 1	8
507	Delphi, Athenian Treasury	2 in-antis	31 8½	31 9½	1:463	7 1½	2 6	13 6½	5 3½
c. 500	Metapontum, Tavole Palatine	6 by 12	52 8	109 9	2:021	9 8½, 9 7	3 5½	16 10	12
	Acragas, Heracles	6 .. 15	82 11½	219 11½	2:651	15 1½	6 10	33 0½	12
	Delphi, Athena Pronaea	6 .. 12	43 5½	90 1½	2:073	8 2, 7 11½	3 3½, 3 2½	15 1	?
498	Sunium, Poseidon (old)	6 .. 13	42 10½	99 1	2:312	9 0½	3 2½	?	?
c. 495-485	Aegina, Aphaea	6 .. 12	45 2	94 6½	2:093	8 7, 8 5	3 3	17 3½	6 5½
488-480	Athens, Older Parthenon	6 .. 16	77 2½	219 7½	2:845	14 5½, 14 3½	6 3	?	?
480	Syracuse, Athena	6 .. 14	72 2	180 6	2:502	13 7½, 13 8	6 ½	28 7	12
	Himera, Nike	6 .. 14	73 8	183 7	2:492	13 8½, 13 9½	6 ½	?	?
c. 480-460	Selinus, Hera ('ER')	6 .. 15	83 1	222 2½	2:675	15 5½	7 5½	33 3½	- 14
468-460	Olympia, Zeus	6 .. 13	90 10	210 4½	2:316	17 1½, 17 1½	7 4½, 7 3	34 2½	13 4½
c. 460	Paestum, Poseidon	6 .. 14	79 7½	196 9	2:472	14 8, 14 9½	6 11, 6 8	29 1½	12
	Acragas, Hera Lacinia	6 .. 13	55 6	125 0	2:253	10 3, 10 0½	4 6½, 4 4½	20 10½	9
	Selinus, 'A'	6 .. 14	52 11	132 2½	2:499	9 10	4 4	20 5½	9
c. 450-425	Bassae, Apollo	6 .. 15	47 6	125 5½	2:642	8 10½, 8 9½	3 9½, 3 8½	19 6½	6
449-444	Athens, Hephaestum	6 .. 13	44 11½	104 2½	2:318	8 5½	3 4½	18 9	6 7½
447-432	Athens, Parthenon	8 .. 17	101 3½	228 0	2:251	14 1½, 14 1	6 3	34 2½	10
444-440	Sunium, Poseidon (new)	6 .. 13	44 2½	102 1½	2:311	8 3½	3 5	19 9½	6 7½
440-436	Athens, Ares	6 .. 13	47 0½	108 10	2:313	8 9½	c. 3 7½	c. 20 7	6 7½
437-432	Athens, Propylaea—								
	Central Building	6 amphi-prostyle	69 3½	78 2½	1:128	{ 11 10½ 17 10	5 1½	{ 28 10½ 27 11½	8 11½
	West Wings	3 in-antis	—	—	—	8 2½	3 6½	19 2½	6
436-432	Rhaninus, Nemesis	6 by 12	32 9½	70 3½	2:143	6 3	2 4½	13 5½	4 6½
c. 430	Acragas, Concord	6 .. 13	55 6½	129 4	2:329	10 6, 10 6½	4 9	22 0	9
425-417	Delos, Apollo (Athenian)	6 amphi-prostyle	31 9½	55 9½	1:757	6 0½	2 8	15 3	4
424-416	Segesta	6 by 14	75 10	190 5	2:510	14 2½, 14 3½	6 5	30 9	11 4
423-416	Argos, Hera	6 .. 12	56 9½	121 1	2:132	10 8½	4 4	c. 24 3½	c. 8
c. 380	Epidaurus, Asclepius	6 .. 11	38 7	75 8	1:961	7 5½	c. 3 1	c. 17 1	5
366-326	Delphi, Apollo	6 .. 15	71 1½	190 10½	2:684	13 7, 13 4½	5 11	c. 34 9	7 11½
c. 350	Tegea, Athena Alca	6 .. 14	62 11½	156 0	2:478	11 10, 11 9½	5 1	31 1	8 5 1
c. 340	Neinea, Zeus	6 .. 12	65 11	139 7½	2:118	12 3½, 12 3½	5 4½	34 0	6
c. 321	Stratos, Zeus	6 .. 11	54 4	106 4	1:957	10 4½	4 3½	c. 23 3½	4
c. 320	Olympia, Metroum	6 .. 11	34 10	67 10	1:946	6 7	2 9½	?	4
319	Athens, Nicias Monument	6 prostyle	36 4½	49 11	1:372	6 10½	2 9½	16 9	4
c. 460-454 c. 314-280	Delos, Apollo (peripteral)	6 by 13	40 11	c. 93 7½	2:288	7 6½	3 1½	c. 17 1	4
c. 250	Pergamum, Athena Polias	6 .. 10	40 3	71 5	1:774	7 9½	2 5½	17 3	4
c. 170	Pergamum, Dionysus	4 prostyle	22 2½	33 3	1:498	6 7½	2 0½	14 8½	2
c. A.D. 125	Eleusis, Artemis Propylaea	4 amphi-prostyle	c. 21 1½	c. 40 5½	1:915	6 5½	2 7	14 10½	4

APPENDIX I

ONS

- 5 When two dimensions or proportions appear side by side in the same column, the first always refers to the fronts and the second to the flanks; but when variations (other than the contracted corner spacings in Doric buildings) occur within either front or flank, the normal is shown above and the extreme variation below, respectively.
- 6 The height of the entablature is always measured to the top of the corona, omitting the sima which forms in reality part of the roof; but for Asiatic Ionic and Corinthian the total, including the sima, is given in parentheses.

FOR DETAILS SEE
APPENDIX III

Height of Entablature ⁴	Proportions in Lower Diameters			in Axial Spacings		in Column Heights	Entasis	Curvature in plan or elevation
	Axial Spacing	Height of Column	Height of Entablature	Height of Column	Height of Order			
ft. in.								
?	2.76, 3.26	4.08, 5.22	?	1.46, 1.60	?	?	●	
?	2.97, 2.69	4.35, 4.21	?				●	
?	1.88, 1.81			2.12, 2.40	?	?	?	
?	2.21	3.97, 4.34	?	1.79			?	
?	2.21, 2.03	c. 4.32	?	c. 1.96, c. 2.13	?	?	○	
14 8 1/2	2.30, 2.13	4.53, 4.78	2.35, 2.48	1.97, 2.24	2.99, 3.40	1.52	○	
6 7 1/2	2.85, 2.68	5.22	2.21	1.83, 1.95	2.61, 2.78	1.42	○	
?	2.31, 2.28	4.15, 4.40	?	1.80, 1.93	?	?	○	● E
12 11 1/2	2.57, 2.64	4.89	2.32	1.90, 1.85	2.81, 2.72	1.48	○	
?	2.00, 2.15	4.47	?	2.24, 2.08	?	?	○	
12 11 1/2	2.50, 2.57	5.09	2.21	2.04, 1.98	2.92, 2.84	1.43	○	● P
11 2	c. 2.48	c. 4.54, c. 4.77	c. 2.46, c. 2.58	c. 1.83, c. 1.93	c. 2.82, c. 2.97	c. 1.54	?	
21 6 1/2	2.20, 2.23	4.95	2.21	2.25, 2.22	3.25, 3.22	1.45	●	
24 9 1/2	2.03, 2.23	4.51, 4.95	2.01, 2.21	2.22			●	
8 8 1/2	1.98, 2.02	4.26	1.86	2.15, 2.11	3.09, 3.03	1.44	●	
5 3 1/2, 5 5 1/2	2.07	4.84	2.09	2.33	3.34	1.43	●	
?	2.87	5.44	2.13, 2.20	1.90	2.64, 2.67	1.39, 1.40	●	
12 2	2.79, 2.76	4.84	?	1.74, 1.76	?	?	●	
?	2.21	4.84	1.78	2.18	2.99	1.37	●	
?	2.47, 2.48	4.58, 4.72	?	1.85, 1.90	?	?	●	
?	2.50	?	?	?	?	?	●	
6 5 1/2, 6 8 1/2	2.65, 2.59	5.32	1.99, 2.06	2.01, 2.05	2.76, 2.86	1.37, 1.39	●	
?	2.32, 2.29	?	?	?	?	?	●	
12 9 1/2	2.11, 2.12	4.54	2.03	2.10, 2.09	3.04, 3.03	1.45	●	
?	2.23, 2.24	?	?	?	?	?	●	
14 8	2.08	4.48	1.97	2.15	3.10	1.44	?	
13 4 1/2, 13 7	2.32, 2.37	4.64, 4.72	1.81, 1.88	2.00, 1.99	2.78, 2.79	1.39, 1.40	●	
12 5	2.12, 2.21	4.20, 4.36	1.79, 1.86	1.99, 1.97	2.83, 2.81	1.43	●	
9 6	2.25, 2.10	4.59, 4.77	2.09, 2.18	2.04, 2.08	2.97, 3.02	1.45	●	
9 1 1/2	2.27	4.72	2.11	2.08	3.01	1.45	●	
6 4 1/2	2.14, 2.38	5.13, 5.31	1.67, 1.74	2.19, 2.23	2.91, 2.96	1.33	○	
6 7 1/2, 6 6	2.54	5.61	1.98, 1.95	2.21	2.99, 2.98	1.35	○	
10 9 1/2	2.25	5.48	1.73	2.43	3.19, 3.20	1.32	○	
6 7 1/2, 6 6 1/2	2.42	5.78	1.93, 1.91	2.39	3.19, 3.18	1.33	○	
6 7 1/2, 6 5 1/2	2.45	5.70	1.84, 1.79	2.33	3.09, 3.06	1.32, 1.31	○	
8 11 1/2, 8 10 1/2	2.33	5.65	1.75, 1.74	2.43, 2.35	3.18, 3.10	1.32, 1.31	○	
6 3 1/2	2.49	5.47		1.62, 1.57	2.12, 2.07		○	
4 6 1/2, 4 5 1/2	2.33	5.45	1.78	2.33	3.10	1.33	○	
9 8 1/2	2.67	5.74	1.95, 1.90	2.15	2.89, 2.87	1.34, 1.33	○	
4 10	2.20, 2.21	4.61	2.04	2.10, 2.09	3.02, 3.01	1.44	○	
	2.25	5.71	1.81	2.54	3.34	1.32	○	
11 9	2.23	4.79	1.83	2.16, 2.15	2.99, 2.97	1.38	○	
c. 8 1 1/2	2.47	c. 5.61	c. 1.88	c. 2.27	c. 3.02	c. 1.33		
5 0	c. 2.44	c. 5.59	c. 1.63	c. 2.29	c. 2.96	c. 1.29		
?	2.29, 2.26	c. 5.86	?	c. 2.56, 2.59	?	?		
7 11 1/2, 7 8 1/2	2.33, 2.31	6.11	1.56, 1.52	2.62, 2.64	3.29, 3.30	1.6, 1.25		
8 5, 8 1 1/2	2.29	6.35	1.57, 1.52	2.76, 2.77	3.45, 3.43	1.5, 1.24		
6 9 1/2	2.42	c. 5.42	1.58	c. 2.24	c. 2.89	c. 1.29		
4 10 1/2	2.36	?	1.75	?	?	?		
4 9 1/2	2.48	6.05	1.74	2.44	3.14	1.29		
4 0 1/2	2.42	c. 5.50	1.30	c. 2.27	c. 2.80	c. 1.24		
4 0	3.14	6.98	1.62	2.22	2.74	1.23		
2 9 1/2	3.26	7.24	1.37	2.22	2.64	1.19		
4 7 1/2	2.53	5.76	1.81	2.29	3.01	1.31		

no curve in floor but curved pediment

2 of 2

Date	Name of Temple	No. of Columns	Top of Stylobate		Ratio Width to Length	Axial Spacing	Lower Column Diameter	Height of Column	Height of Entablature	S
			Front	Flank						
IONIC										
360-460	Ephesus, Artemis (old)	8 (9) by 21	180 9	377 9	2.090	$\left\{ \begin{array}{l} 18 \frac{11}{16}, 17 \frac{1}{2} \\ 28 \frac{3}{4}, 19 \frac{3}{4} \end{array} \right.$	$\left\{ \begin{array}{l} 4 \frac{11}{16} \\ 5 \frac{8}{16}, 4 \frac{11}{16} \end{array} \right.$	39 7½	?	$\left\{ \begin{array}{l} 3 \frac{1}{2} \\ 4 \frac{1}{2} \end{array} \right.$
330-100	Samos, Hera	8 (9) .. 24	195 10½	379 11	1.940	$\left\{ \begin{array}{l} 21 \frac{6}{16}, 15 \frac{5}{16} \\ 27 \frac{7}{16}, 16 \frac{2}{16} \end{array} \right.$	$\left\{ \begin{array}{l} 2, 6 \frac{1}{16} \\ 6 \frac{7}{16}, ? \end{array} \right.$	?	?	$\left\{ \begin{array}{l} 4 \frac{1}{2} \\ 4 \frac{1}{2} \end{array} \right.$
450-425	Locri Epizephyrii, Maraza	6 (7) .. 17	56 10	143 5½	2.525	$\left\{ \begin{array}{l} 11 \frac{6}{16}, 8 \frac{8}{16} \\ 5 \frac{6}{16} \end{array} \right.$	3 8½	?	?	$\left\{ \begin{array}{l} 3 \frac{1}{2} \\ 3 \frac{1}{2} \end{array} \right.$
449	Athens, Ilissus	4 amphiprostyle	19 2½	41 7½	2.169	5 6	1 9½	14 8½	3 7½	
427-424	Athens, Athena Nike	4 amphiprostyle	17 8½	26 9½	1.513	5 1	1 8½	13 3½	3 6½	
421-405	Athens, Erechtheum— North Portico	4 prostyle	35 2	—	—	$\left\{ \begin{array}{l} 10 \frac{2}{16}, 10 \frac{0}{16} \\ 10 \frac{4}{16} \end{array} \right.$	2 8½	25 0½	5 6	$\left\{ \begin{array}{l} 3 \frac{1}{2} \\ 3 \frac{1}{2} \end{array} \right.$
	East Portico	6 prostyle	38 2	—	—	6 11½	2 3½	21 7½	5 0½, 4 11½	
	West Front	4 in-antis	—	—	—	6 1½	2 0½	18 5	5 0½	
335-350	Halicarnassus, Mausoleum	9 by 11	86 7	106 10½	1.234	10 1½	3 7½	31 10	6 7 10½ (8 8½)	
340-156	Priene, Athena Polias	6 .. 11	64 1	121 1½	1.903	11 7	4 2½	37 5	5 6½ (6 9½)	
356-236	Ephesus, Artemis (new)	8 (9) .. 21	168 9	365 9	2.167	$\left\{ \begin{array}{l} 18 \frac{11}{16}, 17 \frac{1}{2} \\ 28 \frac{3}{4}, 19 \frac{3}{4} \end{array} \right.$	6 0½	37 11	?	$\left\{ \begin{array}{l} 3 \frac{1}{2} \\ 2 \frac{1}{2} \end{array} \right.$
350-300	Sardis, Artemis-Cybele	8 .. 20	150 0	325 4	2.168	$\left\{ \begin{array}{l} 17 \frac{4}{16}, 16 \frac{5}{16} \\ 23 \frac{1}{16}, 16 \frac{8}{16} \end{array} \right.$	6 2½	58 2½	?	$\left\{ \begin{array}{l} 3 \frac{1}{2} \\ 3 \frac{1}{2} \end{array} \right.$
13-A.D. 41	Didyma, Apollo	10 .. 21	167 9	358 8½	2.138	17 4½, 17 4½	6 7½	64 8	?	
280	Messa, Aphrodite	8 .. 14	72 6	130 5	1.791	9 7½	3 5	?	7 9 (8 6½)	
250	Chryse, Apollo	8 .. 14	74 1	132 8	1.791	9 9½	3 10½	?	7 5 (8 6)	
193	Teos, Dionysus	6 .. 11	61 1½	114 10½	1.878	10 8½	3 4½	?	6 1½ (7 2½)	
175	Magnesia, Artemis Leucophryene	8 .. 15	103 8	189 11	1.832	$\left\{ \begin{array}{l} 12 \frac{11}{16} \\ 17 \frac{2}{16}, 12 \frac{11}{16} \end{array} \right.$	4 6½	?	8 2½ (9 8½)	$\left\{ \begin{array}{l} 3 \frac{1}{2} \\ 3 \frac{1}{2} \end{array} \right.$
A.D. 125	Aphrodisias, Aphrodite	8 .. 13	65 5	106 10	1.633	$\left\{ \begin{array}{l} 8 \frac{5}{16} \\ 9 \frac{4}{16}, 8 \frac{5}{16} \end{array} \right.$	3 8½	30 5½	7 1½ (7 11½)	$\left\{ \begin{array}{l} 2 \frac{1}{2} \\ 2 \frac{1}{2} \end{array} \right.$
	Aezani, Zeus	8 .. 15	70 0½	120 0½	1.714	$\left\{ \begin{array}{l} 8 \frac{3}{16} \\ 12 \frac{3}{16}, 8 \frac{3}{16} \end{array} \right.$	3 2	31 4	6 3½ (7 2½)	$\left\{ \begin{array}{l} 3 \frac{1}{2} \\ 3 \frac{1}{2} \end{array} \right.$
CORINTHIAN										
15-510	Athens, Zeus Olympius	8 .. 20	134 10½	354 0	2.624	18 0½, 18 2½	6 3½	55 5	?	
14-A.D. 132	Sagalassus, Antoninus Pius	6 .. 11	45 6½	87 4½	1.920	8 3½	2 7	?	5 0½ (5 10)	
A.D. 140	Euromus, Zeus	6 .. 11	47 2	90 1	1.909	8 7	2 10½	27 3	5 6½ (6 3)	
	Cnidus	4 .. 8	26 4	48 0	1.823	7 9, 6 5	2 1	?	7 0 (4 7½)	

APPENDIX II

Height of Column	Height of Entablature	Proportions in Lower Diameters			in Axial Spacings		in Column Heights	Entasis	Curvature
		Axial Spacing	Height of Column	Height of Entablature	Height of Column	Height of Order			
39 7½	?	{ 3.82, 3.46 4.99, 3.89 ?, 2.52 4.17, 2.68 2.33 3.19, 2.33	{ c. 8.00 c. 7.00, c. 8.00	?	{ c. 2.09, c. 2.31 c. 1.40, c. 2.05	?	?		
?	?		?	?	?	?	?		
?	?		?	?	?	?	?		
14 8½	3 7½	3.09	8.25	2.02	2.67	3.32	1.25		
13 3½	3 6½	2.99	7.82	2.08	2.61	3.31	1.26		
25 0½	5 6	{ 3.79, 3.76 3.85, 3.76	9.35	2.05	{ 2.42, 2.49 2.46, 2.49	{ 2.96, 3.03 3.01, 3.03	1.22		
21 7½	5 0½, 4 11½	3.05	9.52	2.22, 2.18	3.12	3.84	1.23		
18 5	5 0½	3.18	9.05	2.48	2.85	3.63	1.27		
31 10	c. 7 10½ (8 8½)	2.80	8.79	2.17, (2.40)	3.14	3.92 (4.00)	1.25 (1.27)		
37 5	5 0½ (6 9½)	2.74	8.84	1.32 (1.61)	3.23	3.71 (3.82)	1.15 (1.18)		
57 11	?	{ 3.14, 2.84 4.68, 3.20 2.66, 2.52 3.54, 2.55	c. 9.60	?	{ c. 3.06, c. 3.34 c. 2.05, c. 3.00 3.36, 3.56 2.52, 3.49	?	?		
58 2½	?		8.95	?		?	?		
64 8	?	2.62	9.74	?	3.72	?	?		
?	7 9 (8 6½)	2.83	?	2.27 (2.51)	?	?	?		
?	7 5 (8 6)	2.52	?	1.81 (2.08)	?	?	?		
?	6 1½ (7 2½)	3.17	?	1.82 (2.14)	?	?	?		
?	8 2½ (9 8½)	2.84	?	1.80 (2.13)	?	?	?		
30 5½	7 1½ (7 11½)	{ 3.84, 2.84 2.29 2.54, 2.29	8.23	1.93 (2.15)	{ 3.60 3.24, 3.60 3.79	{ 4.44 (4.54) 4.00, 4.44 (4.54) 4.55 (4.66)	1.23 (1.26) 1.20 (1.23)		
31 4	6 3½ (7 2½)	{ 2.61 3.88, 2.61	9.91	1.99 (2.27)	{ 2.55, 3.79				
55 5	?	2.86, 2.89	8.81	?	3.07, 3.05	?	?		
?	5 0½ (5 10)	3.20	?	1.95 (2.25)	?	?	?		
27 3	5 6½ (6 3)	3.00	9.52	1.94 (2.18)	3.17	3.82 (3.90)	1.20 (1.23)		
?	7 0 (4 7½)	3.73, 3.09	?	1.92 (2.22)	?	?	?		

APPENDIX III

Temples with certain, probable, uncertain, unlikely, no entasis

All orders are listed using
Dinsmoor's sequence.

Code: (Initial is followed by page reference
and measurements cited.)

C - Coulton
D - Dinsmoor
Dö - Dörpfeld
G - Goodyear
KP Koldewey & Puchstein
P - Penrose
R - Robertson

The first column lists west colonial (Magna Graecia) Temples.

The middle column lists mainland and island Temples.

The third column lists Eastern Temples.

(?) indicates a clash with the other authorities or doubt.

UPWARD
CURVATURE● YES
○ NO

DORIC TEMPLES

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APPENDIX III

Location	Temple	with entasis	probable	uncertain	prob. not	no	references
OLYMPIA, Heraeum		X					C176(1/140ch)Dö.pl21.1
SYRACUSE, Apollo				X			G132; KP63;
SYRACUSE, Olympieum						X	G132; KP67;
SELINUS, 'C'					X		G132; KP99;
ASSOS, Athena							
CORINTH, Apollo						X	D89;
SELINUS, 'D'		X					G132; KP108;
PAESTUM, Basilica		X					L127, 128, 170 (2 1/8") D94, 169 (2 1/8"); C110-76
SELINUS, 'FS'				X			G132; KP13; R116; G132; KP119
ATHENS, Athena (Peisist.)							
SELINUS, Apollo ('GT')		X					D175-6
ACRAGAS, Zeus Olympius							
PAESTUM, Demeter (Ceres) Athena		X					D94-5; KP19; G132; C176 ¹ / ₁₆
DELPHI, Athenian Treasury							
METAPONTUM, Tavole Paladine		X					Dxx111; R116; G132; KP36
ACRAGAS, Heracles		X					G132; KP148;
DELPHI, Athena Pronaea							
SUNIU, Poseidon (old)							
AEGINA, Aphaea							
ATHENS, Older Parthenon							
SYRACUSE, Athena		X					G132; KP69
HIMERA, Nike							
SELINUS, Hera ('ER')				X			G132; KP130;

UPWARD
CURVATURE

YES
NO

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APPENDIX III - 2

		with	probable	uncertain	prob. not	no	
Location	Temple	entasis					references
OLYMPIA, Zeus							
PAESTUM, Poseidon		X					G100, 132; KP26; L27;
ACRAGAS, Hera Lacinia				X			G132; KP169;
SELINUS, 'A'							
BASSAE, Apollo						X	D156; L171; G?151;
ATHENS, Hephaestus		X					L170(-2/3"), p178b; P
ATHENS, Parthenon		X					L170(2/3+");
SUNIUM, Poseidon (new)							D164, 168(11/16"); C176 ₁₀₀
ATHENS, Ares							G99(2/3")
ATHENS, Propylaea - West		X					L171;
Central		X					D168(3/4");
Ionic		X					D169(1/4");
RHAMNUS, Nemesis							
ACRAGAS, Concord		X					G132, 151; KP173;
DELOS, Apollo (Athenian)							
SEGESTA (cols unfinished)				X			G132; KP134;
ARGOS, Hera							
EPIDAUROS, Asclepius							
DELPHI, Apollo							
TEGEA, Athena Alea							
NEMEA, Zeus							
STRATOS, Zeus							
OLYMPIA, Metroum							
ATHENS, Nicias Monument							
DELOS, Apollo (peripteral)							

UPWARD CURVATURE	YES NO	Location	Temple	with	probable	uncertain	prob. not	no	references
			PERGAMUM, Athena Pol.						
			PERGAMUM, Dionysus						
			ELEUSIS, Artemis Propyl.						
			IONIC TEMPLES						
			EPHESUS, Artemis (old)						
			SAMOS, Hera						
			LOCRI EPIZEPHRII, Mazara						
			ATHENS, Ilissus						
			ATHENS, Athena Nike					X	D168; R116; G151;
			ATHENS, Erechtheum North	X					D168; L171(- $\frac{1}{4}$ ")
			East					X	D168; R116
			West	X					D168
			HALICARNASSUS, Mausoleum						
			PRIENE, Ath. Polias.	X					R116
			EPHESUS, new Artemis						
			SARDIS, Artemis-Cyb.						
			DIDYMA, Apollo						
			MESSA, Aphrodite						
			CHRYSE, Apollo						
			TEOS, Dionysus						
			MAGNESIA, Art. Leuco.						
			APHRODIAS, Aphrodite						
			AEZANI, Zeus						
			CORINTHIAN TEMPLES						
			ATHENS, Zeus Olympius	X					D169 (1 $\frac{7}{16}$ ");
			SAGALASSUS, Ant. Pius						
			EUROMUS, Zeus						
			CNIDUS						

APPENDIX IV



The Stecchini Theory

Stecchini advances his theory in his Appendix to Secrets of the Great Pyramid. The Appendix is concerned with other matters so his discussion of the Doric and Egyptian columns is brief and he offers no proof per se. Nevertheless, his study is so highly specialized, that it seems preferable to limit its treatment to the following quotations. His basic tenet is that the Egyptians made their early column a map of Northern and Southern Egypt and the Greeks borrowed this column and made it their most conservative order with a capital of one unit (the Delta) and a shaft of six units.

In the Greek orders the base of the column preserves the arrangement on three horizontal lines, which are the symbol of the Tropic of Cancer (parallels $24^{\circ}06'$, $24^{\circ}00'$, and $23^{\circ}51'$ north). The column basically represents the three meridians of Egypt and through its curvature suggests the extension of the system of meridians to the east and west of Egypt. But since the column is circular, the structure of the column was related to the problem of representing the map of Egypt as part of a cylindrical projection of the surface of the earth from the equator to latitude $31^{\circ}06'$ or latitude $31^{\circ}30'$ north.

The elaborate numerical rules for the proportions of Greek columns, which archaeologists treat as numerological superstitions, can be explained when one considers the two interrelated problems of describing mathematically the curvature of the earth and of projecting a curved surface on a flat map. The theory of conic sections, which is considered the highest achievement of Greek mathematics, may have been developed in order to solve these problems. Greek columns taper from the bottom to the top, but the rectilinear line of the shrinking there is applied a curved line, so that the column swells to swell slightly toward the middle. If we

consider the scheme I have presented for the calculation of the lengths of the degrees, a scheme in which a basic simple progression was modified by the addition of another progression, we can understand why Greek columns diminished in diameter from bottom to top according to the combination of two lines. In the case of the columns of the Parthenon, the added curvature, called entasis by the Greeks, is a hyperbolic curve, but in other temples we meet with more complex mathematical curves.

It may be enough to say this much here: if one assumes that the bottom of the colonnade of the Parthenon represents the equator and its top the latitude of Athens, the proportions of the entire colonnade can be readily explained.¹

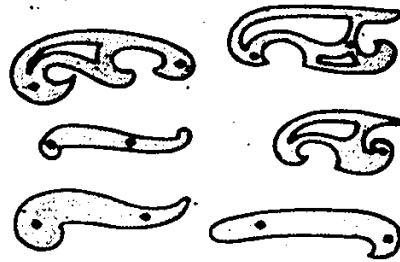
Let us remember that the Parthenon columns are unique; The vertex of their curve is excluded from the column and occurs precisely two diameters below the stylobate.²

¹Stecchini, pp. 331-332, (my emphasis).

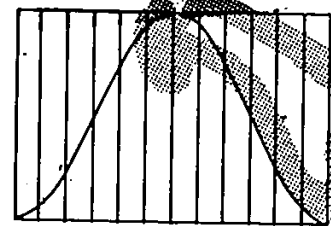
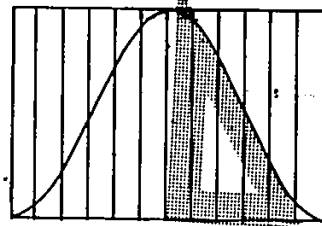
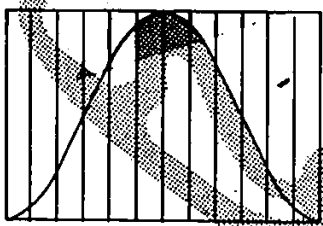
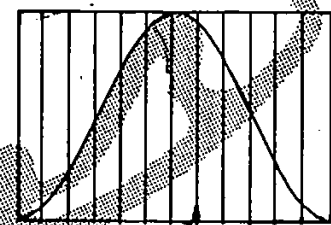
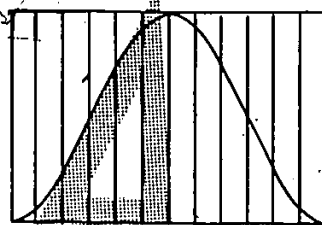
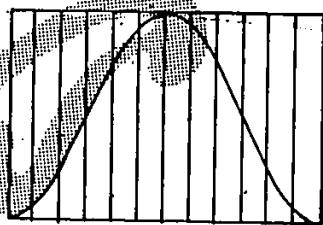
²Penrose, p.42.

Drawing Techniques Used in Describing Curves - General**IRREGULAR CURVES**

For drawing curved lines in which, unlike circular arcs, the radius of curvature is not constant, an instrument known as an irregular curve or French curve is used. The patterns for these curves are based on various combinations of ellipses, spirals, and other mathematical curves. The curves are available in a variety of shapes and sizes. Generally, the draftsman plots a series of points of intersection along the desired path, then uses the French curve to join these points so that a smooth-flowing curve results. ¹



Irregular Curves



There is no reason to believe the Greeks did not also use 'French curves', dividers, drawing instruments, templates, as well as string and tacks to describe certain curves.

¹Jensen, C.H., Engineering Drawing and Design, McGraw-Hill, Toronto, 1968, pp.20-21.

Appendix VI

The Ellipse

THE ELLIPSE

The *ellipse* is the plane curve generated by a point moving so that the sum of the distances from any point on the curve to two fixed points, called *foci*, is a constant.

Often a draftsman is called upon to draw oblique and inclined holes and surfaces which take the form of an ellipse. Several methods, true and approximate, are used for its construction. The terms *major diameter* and *minor diameter* will be used in place of major axis and minor axis in order that the reader will not become confused with the mathematical X and Y axes.

TO DRAW AN ELLIPSE — TWO CIRCLE METHOD

1. Given the major and minor diameters, construct two concentric circles with diameters equal to AB and CD .
2. Divide the circles into a convenient number of equal parts. Figure 3.23 shows 12.

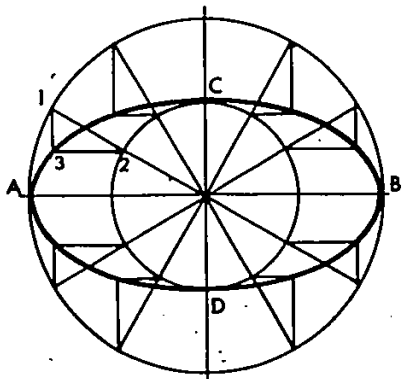


Fig. 3.23 Drawing an Ellipse — Two Circle Method

3. Where the radial lines intersect the outer circle, as at 1, draw lines parallel to line CD inside the outer circle.

4. Where the same radial line intersects the inner circle, as at 2, draw a line parallel to axis AB away from the inner circle. The intersection of these lines, as at 3, gives points on the ellipse.

5. Draw a smooth curve through these points.

TO DRAW AN ELLIPSE — PARALLELOGRAM METHOD

1. Given the major diameter CD and minor diameter AB , construct a parallelogram.
2. Divide CO into a number of equal parts. Divide CE into the same number of equal parts. Number the points from C .
3. Draw a line from B to point 1 on line CE . Draw a line from A through point 1 on CO intersecting the previous line. The point of intersection will be one point on the ellipse.
4. Proceed in the same manner to find other points on the ellipse.
5. Draw a smooth curve through these points.

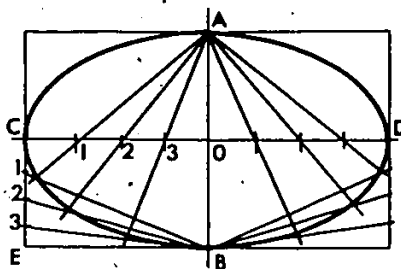


Fig. 3.24 Drawing an Ellipse — Parallelogram Method

TO DRAW AN ELLIPSE — FOUR CENTRE METHOD

1. Given the major diameter CD and the minor diameter AB , join points A and C with a line.
2. Lay off AE equal to $CO - AO$.
3. Draw the right bisector of CE locating point G on line CO and point F on line AB . (Line AB may have to be extended.)
4. Make OF equal to OF_1 and OG equal to OG_1 .
5. Point F , F_1 , G and G_1 are the centres for the two large and two small arcs forming the ellipse.

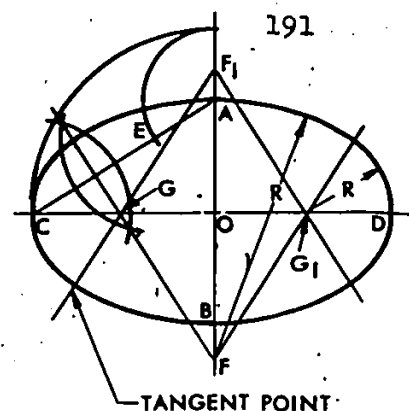


Fig. 3.25 Drawing an Ellipse — Four Centre Method

TO DRAW AN ELLIPSE — THE TRAMMEL METHODS

FIRST METHOD

Given the major diameter CD and the minor diameter AB .

1. On a strip of paper or cardboard mark the distances ao and co as shown.
2. Placing point a on line CD and point c on line AB , mark point o .

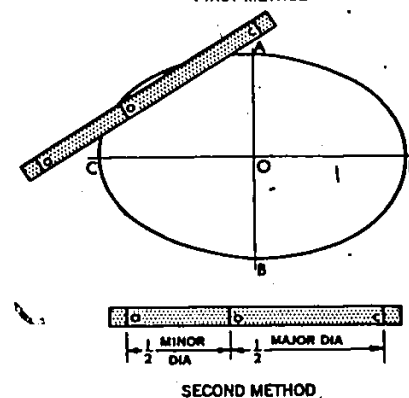
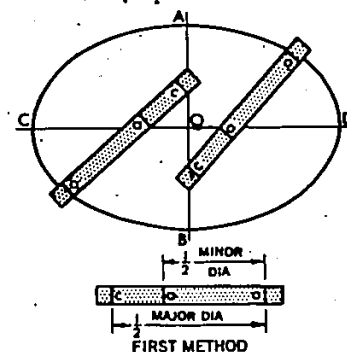


Fig. 3.26 Drawing an Ellipse — Trammel Methods

The Ellipse (continued)

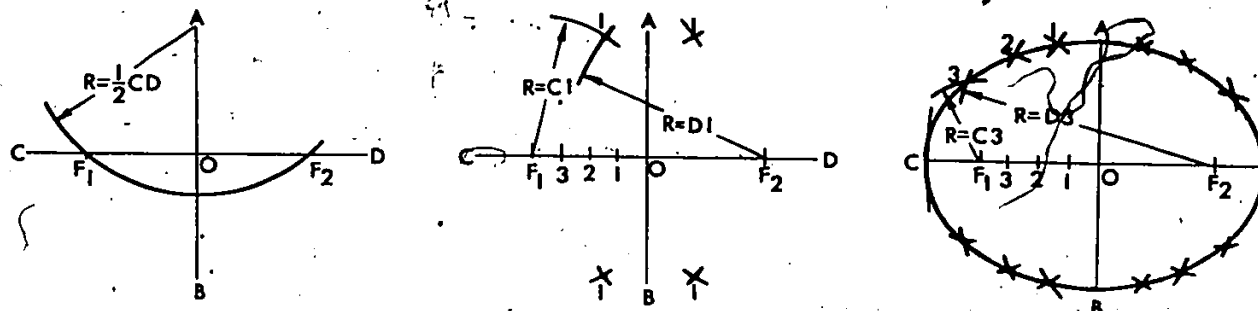


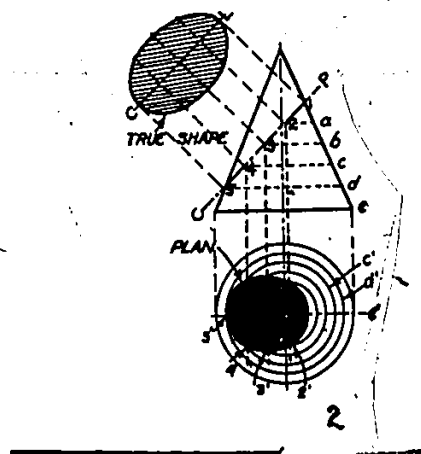
Fig. 3.27 Drawing an Ellipse — Foci Method

3. Reposition the strip to obtain various positions of point o which are located on the ellipse.
4. Connect the points using an irregular curve.

SECOND METHOD

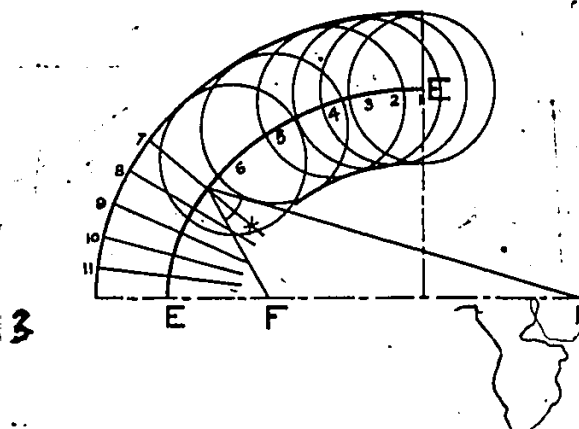
Given the major diameter CD and the minor diameter AB.

1. On a strip of paper or cardboard mark the distances ao and co as shown.
2. Placing point a on line CD and point c on line AB mark point o.
3. Reposition the strip to obtain various positions of point o, which are located on the ellipse.
4. Draw a smooth curve through these points.



TO DRAW AN ELLIPSE — FOCI METHOD

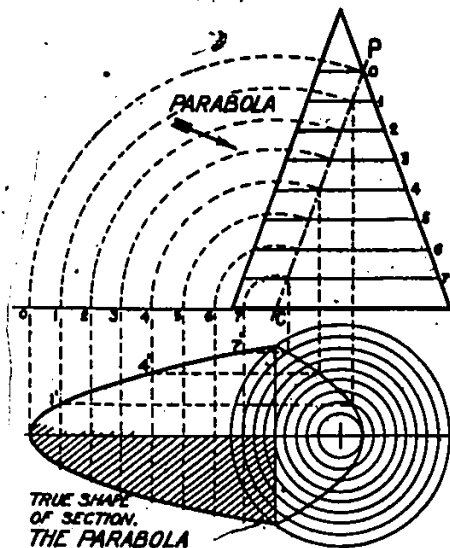
1. Given the major diameter CD and the minor diameter AB, let the diameters intersect at O. Draw an arc with centre A and radius $R = CO$ cutting line CD at F_1 and F_2 . These are the foci of the ellipse.
2. Divide OF_1 into a given number of equal parts. Figure 3.27 shows 4 equal parts.
3. With point F_1 as centre and a radius equal to distance C_1 , draw an arc in the top LH quadrant.
4. With point F_2 as centre and a radius equal to distance D_1 , draw an arc in the top LH quadrant intersecting the first arc at point 1.
5. Using radii equal to distances C_2 and D_2 and centres F_1 and F_2 respectively, plot point 2.
6. Proceed in the same manner to find point 3 and points in the other quadrants.
7. Draw a smooth curve through these points.



¹Jensen, p.40.

²Parkinson, Engineering Workshop Drawing, Pitman, London London, 1941, 32

³Parkinson, p. 26

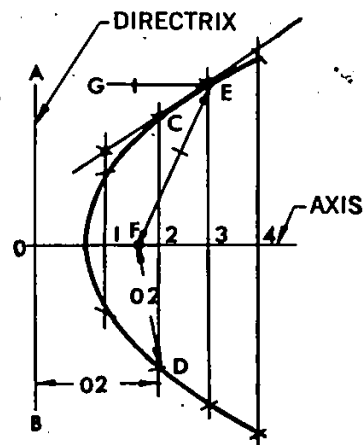


THE PARABOLA

The *parabola* is a plane curve generated by a point that moves along a path equidistant from a fixed line (*directrix*) and a fixed point (*focus*).

TO CONSTRUCT A PARABOLA — TRUE METHOD

1. Given the focus *F* and directrix *AB*, draw a line (*axis*) perpendicular to *AB* through focus *F*.
2. Draw a line parallel to line *AB* intersecting the axis at any point 2.
3. With *F* as the centre and a radius equal to *O2*, strike an arc above and below the axis intersecting the vertical line which passes through point 2. The intersections of these lines, points *C* and *D*, are points on the parabola.
4. Proceed in the same manner to find other points on the parabola.
5. Connect these points using an irregular curve.
6. To draw a tangent at any point *E*. Draw *EG* parallel to the axis to bisect angle *GEF*.



(A) TRUE METHOD

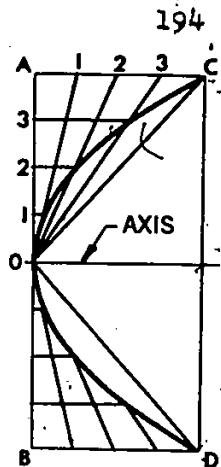
¹Parkinson, p. 32.

²Jensen, p. 41, 42.

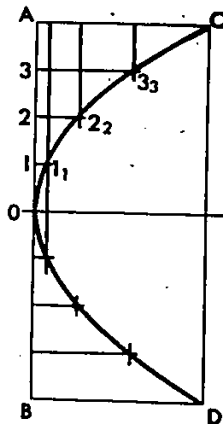
Appendix VI

TO CONSTRUCT A PARABOLA — PARALLELOGRAM METHOD

1. Given the sizes of the enclosing rectangle, distances AB and AC. Construct a parallelogram.
2. Divide AC into a number of equal parts. Divide AO into the same number of equal parts. Number the points as shown.
3. Draw a line from O to point 1 on line AC. Draw a line parallel to the axis through point 1 on line AO intersecting the previous line O1. The point of intersection will be one point on the parabola.
4. Proceed in the same manner to find other points on the parabola.
5. Connect the points using an irregular curve.



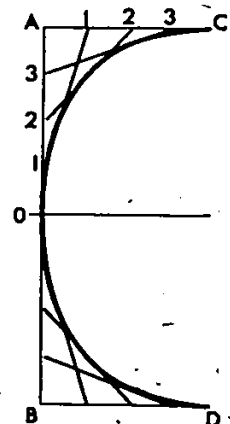
(B) PARALLELOGRAM METHOD



(C) OFFSET METHOD

TO CONSTRUCT A PARABOLA — OFFSET METHOD

1. Given the sizes of the enclosing rectangle, distances AB and AC. Construct a parallelogram.
2. Divide OA into four equal parts.
3. The offsets vary in length as the square of their distances from O. As OA is divided into four equal parts, distance AC will be divided into 4^2 or 16 equal division. Thus as O1 is $\frac{1}{4}$ the length of OA, the length of line 1-1 will be $(\frac{1}{4})^2$ or $\frac{1}{16}$ the length of AC.
4. As distance O2 is $\frac{1}{2}$ the length of OA, the length of line 2-2 will be $(\frac{1}{2})^2$ or $\frac{1}{4}$ the length of AC.
5. As distance O3 is $\frac{3}{4}$ the length of OA, the length of line 3-3 will be $(\frac{3}{4})^2$ or $\frac{9}{16}$ the length of AC.
6. Complete the parabola by joining the points with an irregular curve.



(D) ENVELOPE METHOD

TO CONSTRUCT A PARABOLA — ENVELOPE METHOD

1. Given the sizes of the enclosing rectangle, distances AB and AC. Construct a parallelogram.
2. Divide AC into a number of equal parts. Divide AO into the same number of equal parts.
3. Connect the corresponding numbers.
4. Draw the parabolic curve tangent to these lines.

Appendix VI

THE HYPERBOLA

A *hyperbola* is a curve generated by a point moving so that the difference of its distances from two fixed points, called the *foci*, is a constant.

TO DRAW A HYPERBOLA

1. Given the transverse axis AB and the foci F_1 and F_2 , with F_1 as a centre and a radius greater than AF_2 (Figure 3.31 shows the radius equal to the distance $A1$) strike arcs above and below the transverse axis at C and D .
2. With F_2 as a centre and a radius equal to the distance $B1$, strike arcs above and below the transverse axis intersecting the other arcs at points C and D . Points C and D are two points on the hyperbola.
3. Repeat the above procedure using radii equal to distances $A2$ and $B2$ to locate points E and G on the hyperbola.
4. Repeat for distances $A3$ and $B3$ for points H and J .
5. Draw a smooth curve through these points.

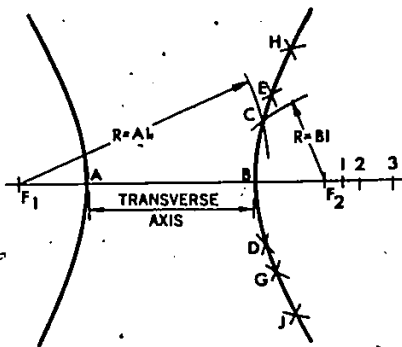
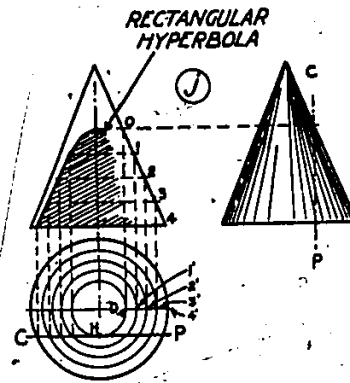


Fig. 3.31 Drawing a Hyperbola



It will be noted that not all curves are considered in this Appendix. There are also various spirals, cycloids, epicycloids and hypocycloids, as well as 'false' ellipses, etc.

The intention of the diagrams is to show the relative simplicity of making the irregular curves with simple tools.

¹Jensen, p.43.

²Parkinson, p.32.

THE HELIX

The *helix* is the curve generated by a point that revolves uniformly around and up or down the surface of a cylinder. The *lead* is the vertical distance the point rises or drops in one complete revolution.

TO DRAW A HELIX

1. Given the diameter of the cylinder and the lead, draw the top and front views.
2. Divide the circumference (top view) into a convenient number of parts (use 12) and label them.
3. Project lines down to the front view.
4. Divide the lead into the same number of equal parts and label them as shown.

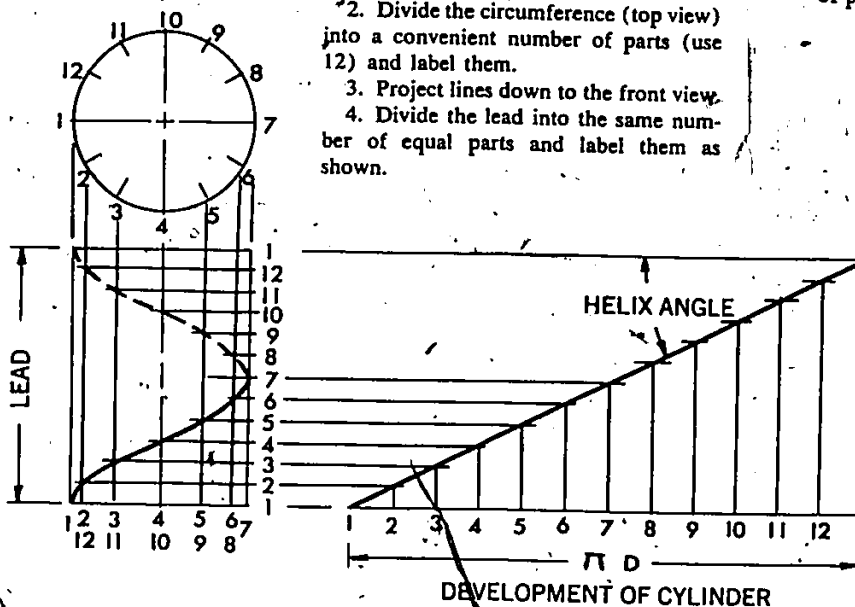


Fig. 3.28 Drawing a Cylindrical Helix

5. The points of intersection of lines with corresponding numbers lie on the helix. *Note:* as points 8 to 12 lie on the back portion of the cylinder, the helix curve starting at point 7 and passing through points 8, 9, 10, 11, 12 to 1 will appear as a hidden line.

6. If the development of the cylinder is drawn, the helix will appear as a straight line on the development.

TO DRAW A CONICAL HELIX

1. Given the diameter and height of the cone and the lead, draw the top and front views.
2. Divide the circumference of the base (top view) into a convenient number of parts (use 8) and label them.

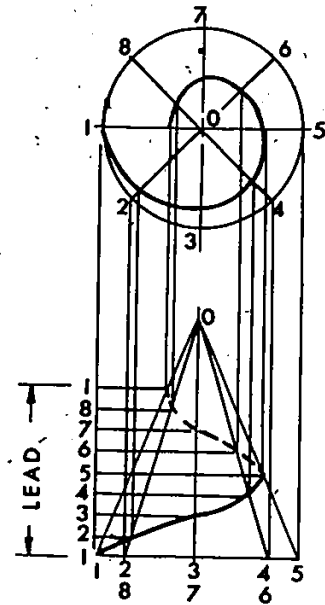


Fig. 3.29 Drawing a Conical Helix

3. Project these points down to the base of the front view and label them.

4. Draw light lines from these points to the apex of the cone.

5. Divide the lead into the same number of equal parts and label them as shown.

6. The points of intersection of lines with corresponding numbers lie on the conical helix. *Note:* as points 8 to 10 lie on the back portion of the cone, the conical helix curve starting at 5 and passing through points 6, 7, 8 to 1 will appear as a hidden line.

Mathematical Test for Vertical Projection of a Helix by Stevens

For large columns the graphic test cannot be readily used, since R , if it is nearly equal to the radius of the column, becomes unwieldy as it must be multiplied by four, just as all the horizontal measurements are. Under such conditions the following mathematical method may be employed:

From the nature of the curve, we know, by consulting figure 7:

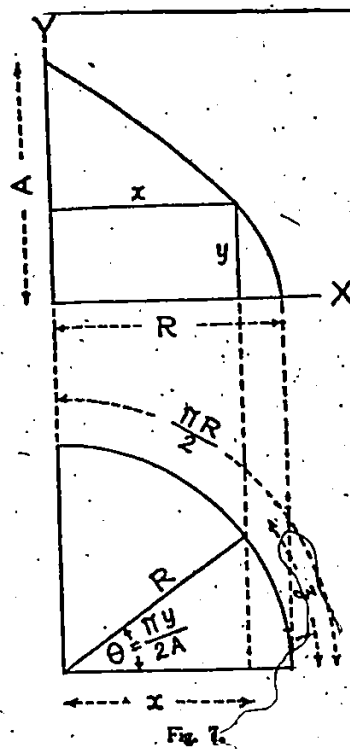


Fig. 7.

that

$$z : y = \frac{\pi R}{2} : A$$

$$z = \frac{\pi R}{2} \frac{y}{A}$$

$$\therefore \angle \theta = \frac{\pi y}{2A}$$

$$\cos \frac{\pi y}{2A} = \frac{x}{R}$$

which is the equation of the vertical projection of a helix. The equation may also be written

$$y = \frac{2A}{\pi} \cos^{-1} \frac{x}{R}$$

Take three known points on the curve, figure 8:

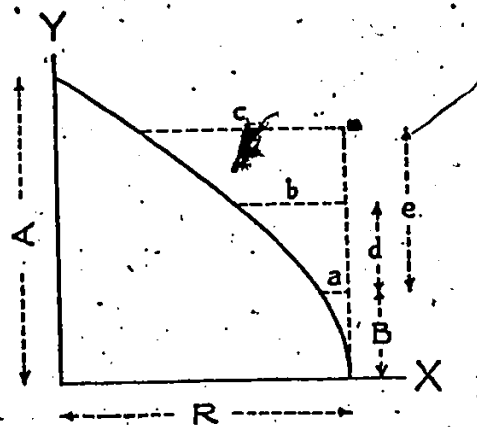


Fig. 8.

Then

$$B = \frac{2A}{\pi} \cos^{-1} \frac{R-a}{R}$$

$$B + d = \frac{2A}{\pi} \cos^{-1} \frac{R-b}{R}$$

$$B + e = \frac{2A}{\pi} \cos^{-1} \frac{R-c}{R}$$

Eliminating B by substitution

$$d = \frac{2A}{\pi} \left(\cos^{-1} \frac{R-b}{R} - \cos^{-1} \frac{R-a}{R} \right)$$

$$e = \frac{2A}{\pi} \left(\cos^{-1} \frac{R-c}{R} - \cos^{-1} \frac{R-a}{R} \right)$$

Eliminating A by division

$$(1). \dots\dots\dots \frac{d}{e} = \frac{\cos^{-1} \frac{R-b}{R} - \cos^{-1} \frac{R-a}{R}}{\cos^{-1} \frac{R-c}{R} - \cos^{-1} \frac{R-a}{R}}$$

an equation in which R is the only unknown quantity, and also an equation in which it is not necessary to know the distance from the horizontal axis to any of the known points. A value of R which satisfies the equation very approximately can be found by trial.

If the nearest point on the curve to the axis of X coincides with the axis of X , both B and a are equal to zero, and equation (1) reduces to

$$(2) \quad \frac{d}{e} = \frac{\cos^{-1} \frac{R-b}{R}}{\cos^{-1} \frac{R-c}{R}}$$

which is convenient for the conditions shown in figure 9.

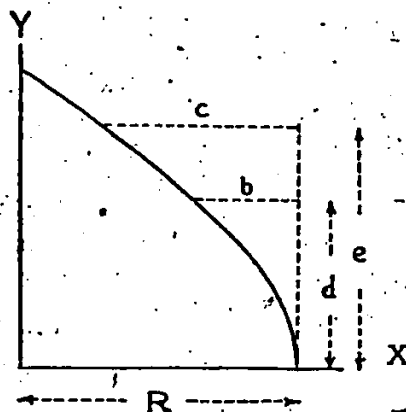


Fig. 9.

If $B=0$ and $e=2d$, as in figure 6, equation (2) becomes

$$\begin{aligned} \frac{1}{2} &= \frac{\cos^{-1} \frac{R-b}{R}}{\cos^{-1} \frac{R-c}{R}} \\ \cos^{-1} \frac{R-c}{R} &= 2 \cos^{-1} \frac{R-b}{R} \\ \frac{R-c}{R} &= \cos \left(2 \cos^{-1} \frac{R-b}{R} \right) = 2 \cos^2 \left(\cos^{-1} \frac{R-b}{R} \right) - 1 \\ &= 2 \left(\frac{R-b}{R} \right)^2 - 1 \\ R^2 - cR &= 2R^2 - 2bR + 2b^2 - R^2 \\ (4b-c)R &= 2b^2 \end{aligned}$$

$$(3) \dots\dots\dots R = \frac{2b^2}{4b - c}$$

This value of R is easily calculated.

Furthermore, from the nature of the curve we know that R can vary only from $\frac{c}{2}$ to ∞ . By inspecting equation (3) we see that,

$$\text{when } R = \frac{c}{2} \\ \frac{c}{2} = \frac{2b^2}{4b - c}$$

$$4bc - c^2 = 4b^2$$

$$4b^2 - 4bc + c^2 = 0$$

$$2b - c = 0$$

$$b = \frac{c}{2}$$

$$\text{and when } R = \infty$$

$$\infty = \frac{2b^2}{4b - c}$$

$$4b - c = 0$$

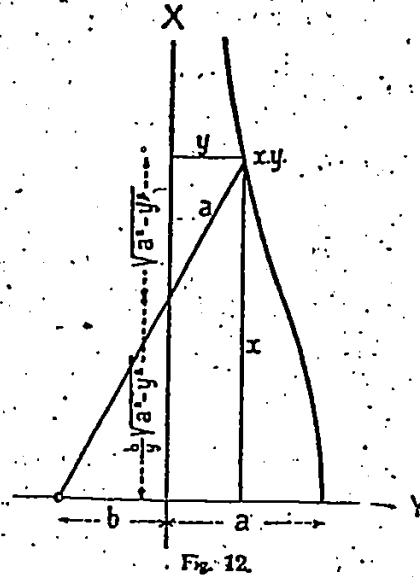
$$b = \frac{c}{4}$$

That is b can vary only between the limits of $\frac{c}{2}$ and $\frac{c}{4}$; in other words, if $b > \frac{c}{2}$ or $b < \frac{c}{4}$ the curve cannot be the vertical projection of a helix.

If the mathematical test gives a value of R equal to the maximum radius of the column or to some other conspicuous measure of the column, and if a number of other points lying on the measured curve also give the same value for R , we may be sure that the entasis is the vertical projection of a helix.

Stevens' Mathematical proof for the Conchoid of Nicomedes

From figure 12 we see that



$$z = \frac{b}{y} \sqrt{a^2 - y^2} + \sqrt{a^2 - y^2}$$

$$xy = (b + y) \sqrt{a^2 - y^2}$$

$$a^2 - y^2 = \frac{x^2 y^2}{(b + y)^2}$$

the equation of the conchoid, an equation of the fourth degree.

The problem before us is to determine that conchoid which most nearly coincides with the entasis. If the entasis is a conchoid, it is a likely supposition that the axis of X of the conchoid coincides with the axis of the column and the axis of Y with the maximum radius next the curve. A preliminary test of this supposition can be made in the following way.

As just stated, if the curve is a conchoid at all, its axes probably coincide with the axis of the column and the maximum radius. Consider the mathematical conchoid, therefore, which has its axis of X coinciding with the axis of the column, its axis of Y coinciding with the maximum radius of the column, and which has the top radius of the column, just before the entasis begins to work into the apophyge, as an ordinate: if a third point on this mathematical curve — for the best results the point should be taken about half way between the maximum radius and ordinate just mentioned — nearly coincides with the measured curve, we shall have a suspicion that the measured curve is a conchoid. But, even if this coincidence is close, many points of the measured curve must be investigated before a definite conclusion can be reached.

Take the above mentioned ordinate, the maximum radius and the distance between these two, and calculate the corresponding value of b in the equation of the conchoid: this particular value of b we shall call b_0 .

(4). Let $b = b_0 + \beta$, where β is the unknown error in the determination of b . If β is a very small quantity, the equation of the conchoid may be reduced to an equation of the first degree¹.

$$a^2 - y^2 = \frac{x^2 y^2}{(b + y)^2} \quad \text{the equation of the conchoid}$$

$$= \frac{x^2 y^2}{(b_0 + \beta + y)^2}$$

$$= \frac{x^2 y^2}{(b_0 + y)^2 \left(1 + \frac{\beta}{b_0 + y}\right)^2}$$

$$= \frac{x^2 y^2}{(b_0 + y)^2} \left(1 + \frac{\beta}{b_0 + y}\right)^{-2}$$

$$= \frac{x^2 y^2}{(b_0 + y)^2} \left(1 - 2 \frac{\beta}{b_0 + y} + \dots\right)$$

$$(5) \dots\dots\dots a^2 - y^2 = \frac{x^2 y^2}{(b_0 + y)^2} - \frac{x^2 y^2}{(b_0 + y)^3} \beta$$

The remaining terms, which contain the increasing powers of β , can be dropped, provided β is very small.

$$(6) \dots\dots\dots \text{Let } a^2 = \alpha \text{ (known only approximately)}$$

$$\text{and } \frac{x^2 y^2}{(b_0 + y)^3} = m$$

$$\text{and } \frac{x^2 y^2}{(b_0 + y)^2} + y^2 = p$$

substituting these values in equation (5), we have

(7). $\alpha + m \beta = p$. This is an equation of the first degree: the problem now becomes one of finding α and β from repeated values of m and p . Taking a series of actual points on the entasis, we have

$$\alpha + m_1 \beta = p_1$$

$$\alpha + m_2 \beta = p_2$$

$$\alpha + m_3 \beta = p_3$$

$$\dots\dots\dots = \dots$$

$$\alpha + m_i \beta = p_i$$

$$(8) \dots\dots\dots i \alpha + \beta \Sigma m = \Sigma p$$

Also

$$m_1 \alpha + m_1^2 \beta = m_1 p_1$$

$$m_2 \alpha + m_2^2 \beta = m_2 p_2$$

$$m_3 \alpha + m_3^2 \beta = m_3 p_3$$

$$\dots\dots\dots = \dots$$

$$m_i \alpha + m_i^2 \beta = m_i p_i$$

$$(9) \dots\dots\dots \alpha \Sigma m + \beta \Sigma m^2 = \Sigma m p$$

Equations (8) and (9) give us a means of finding the values of α and β ; after which a is obtained from equation (6), and b from equation (4). If the value of a very closely approximates the maximum radius of the column, and if the value of β is small in relation to b , we may feel fairly sure that the entasis is a conchoid. But before coming to this conclusion we must push the calculations still further to be sure that there is no point on the measured curve which does not radically depart from the theoretical conchoid.

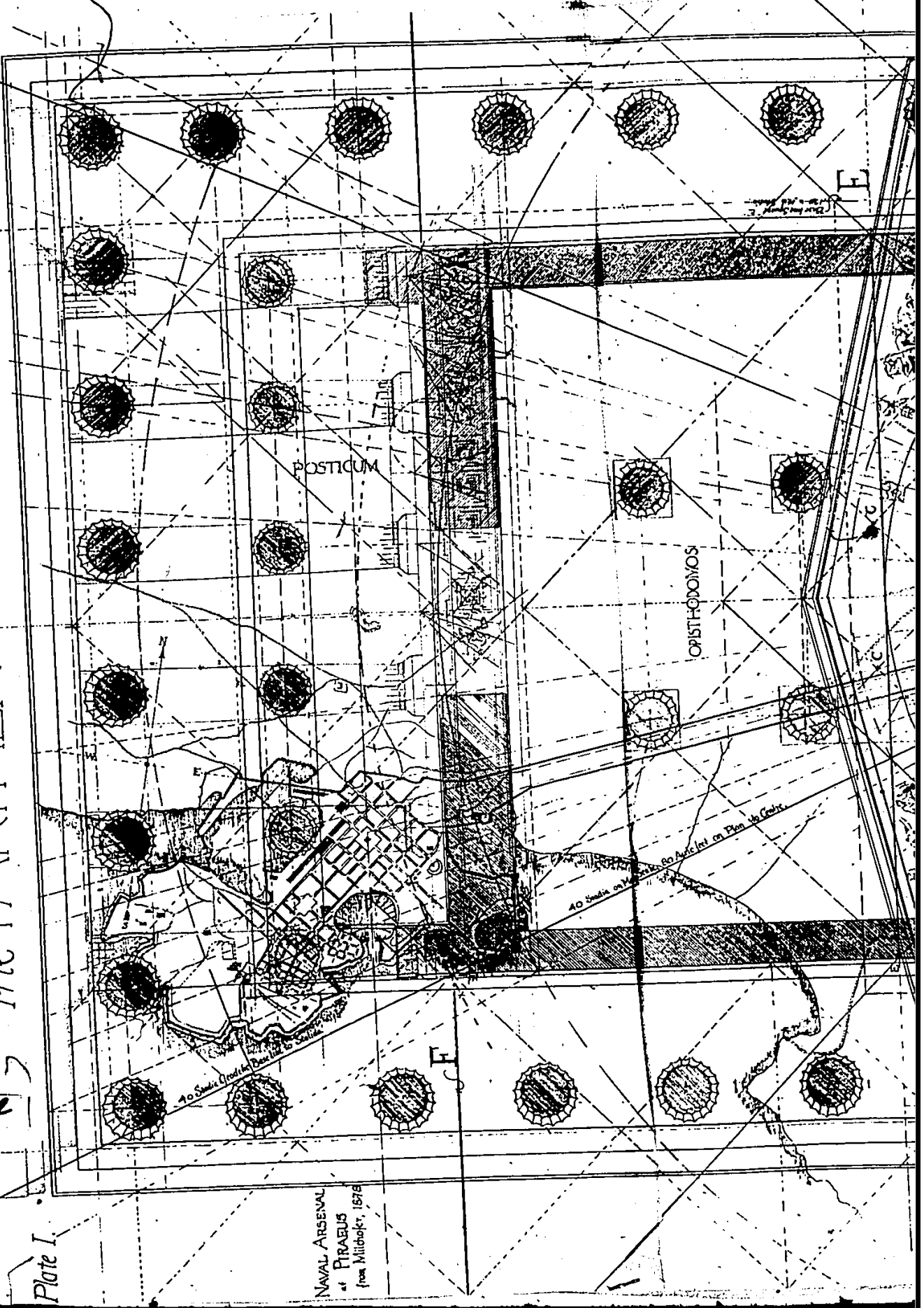
It is obvious, that, the greater the number of readings, the surer we are of the investigations — in fact, a few readings may give an entirely erroneous result.

POOR COPY.

The PARTHENON at ATHENS.

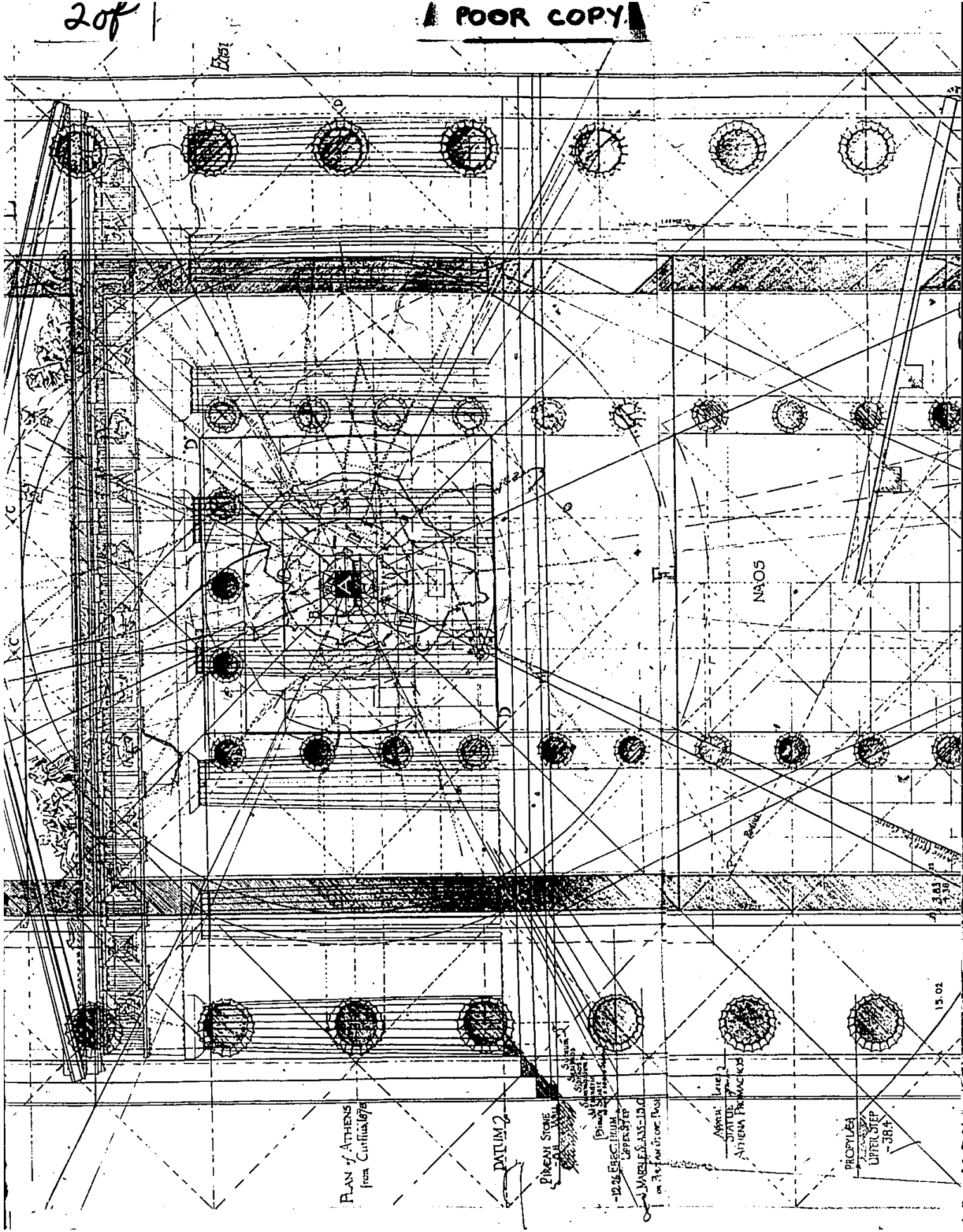
1 of 7

Plate I.



NAVAL ARSENAL
at PIRAEUS
from Milliot, 1878

East



PLAN of ATHENS
from Cutilia 1778

DATUM 2

PURE STONE
ON WALL

-12.26 ERECTIUM
UPPER STEP

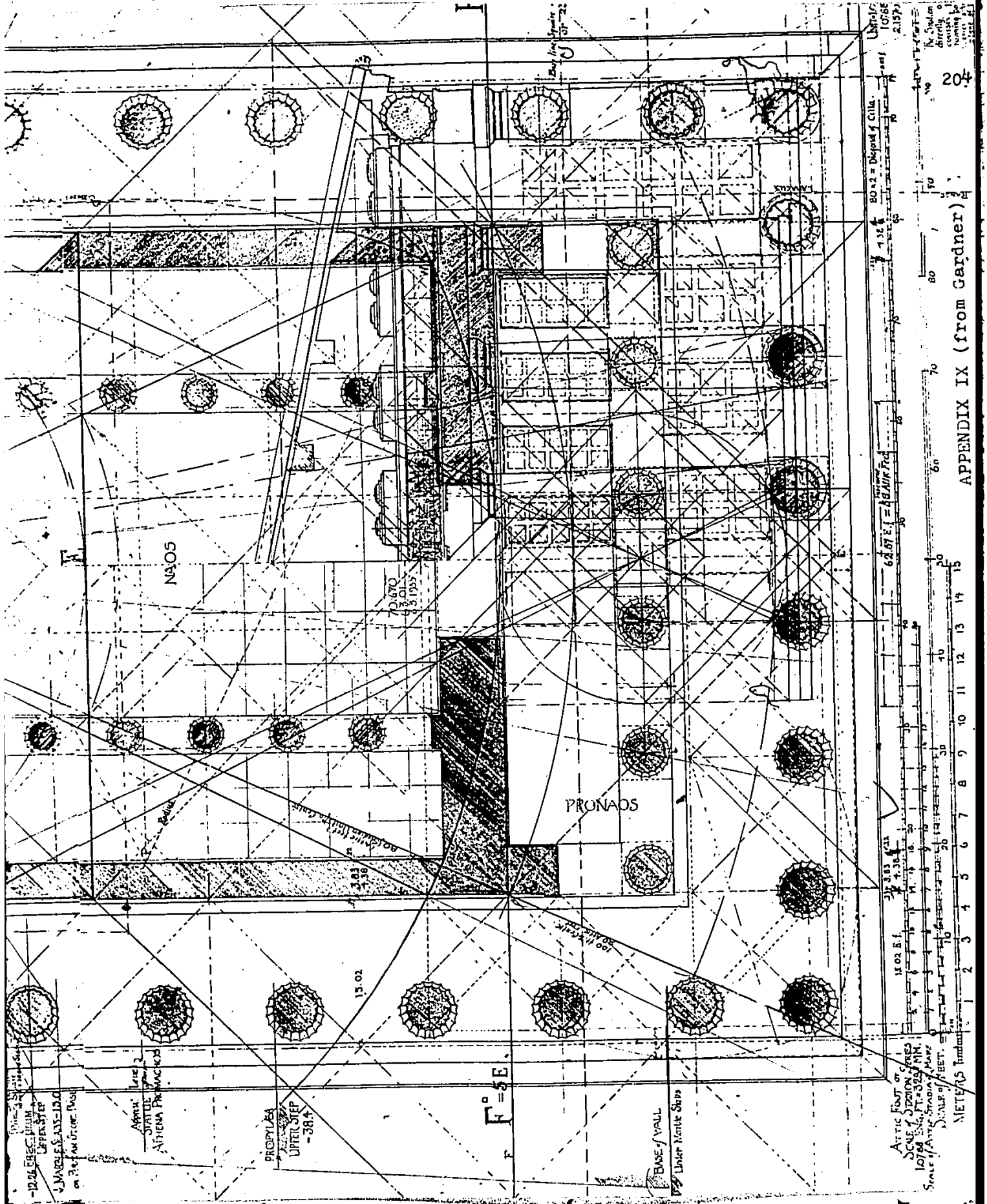
WALLS 13.15-13.10
on the same level

APPROX. LINE 2
DUTY OF
ANTENNA FRANCHISE

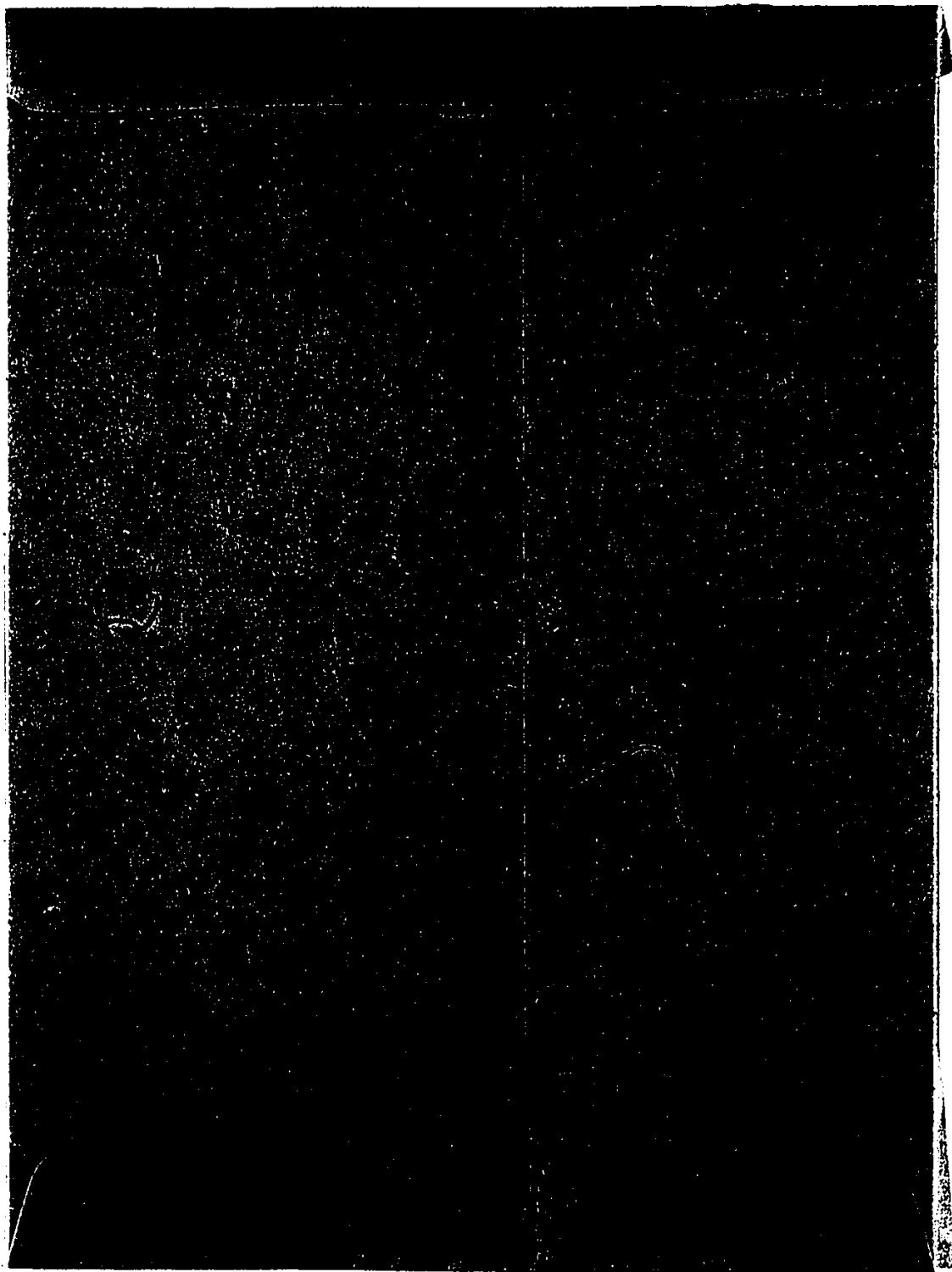
PROPYLEA
UPPER STEP
-38.4

N3.05

13.01



Overlays (acetate) of Stevens' Studies of Roman Entasis
(Figures 14 to 20 inclusive)



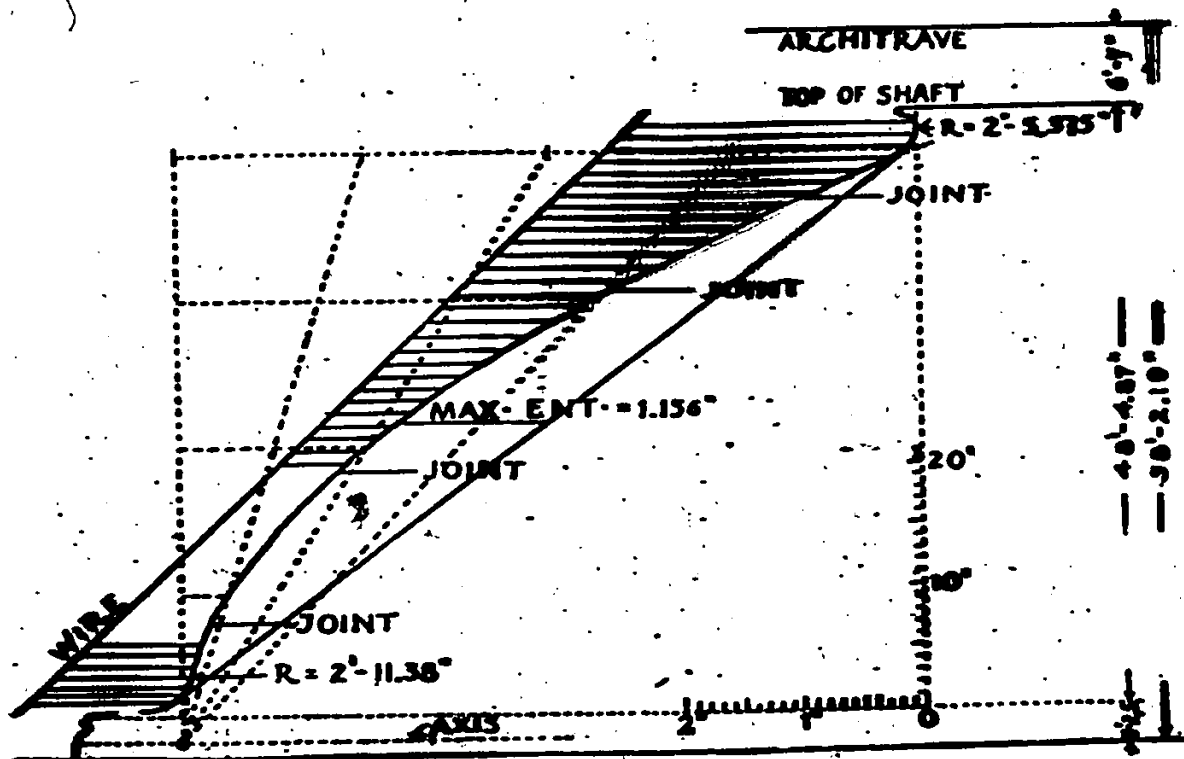
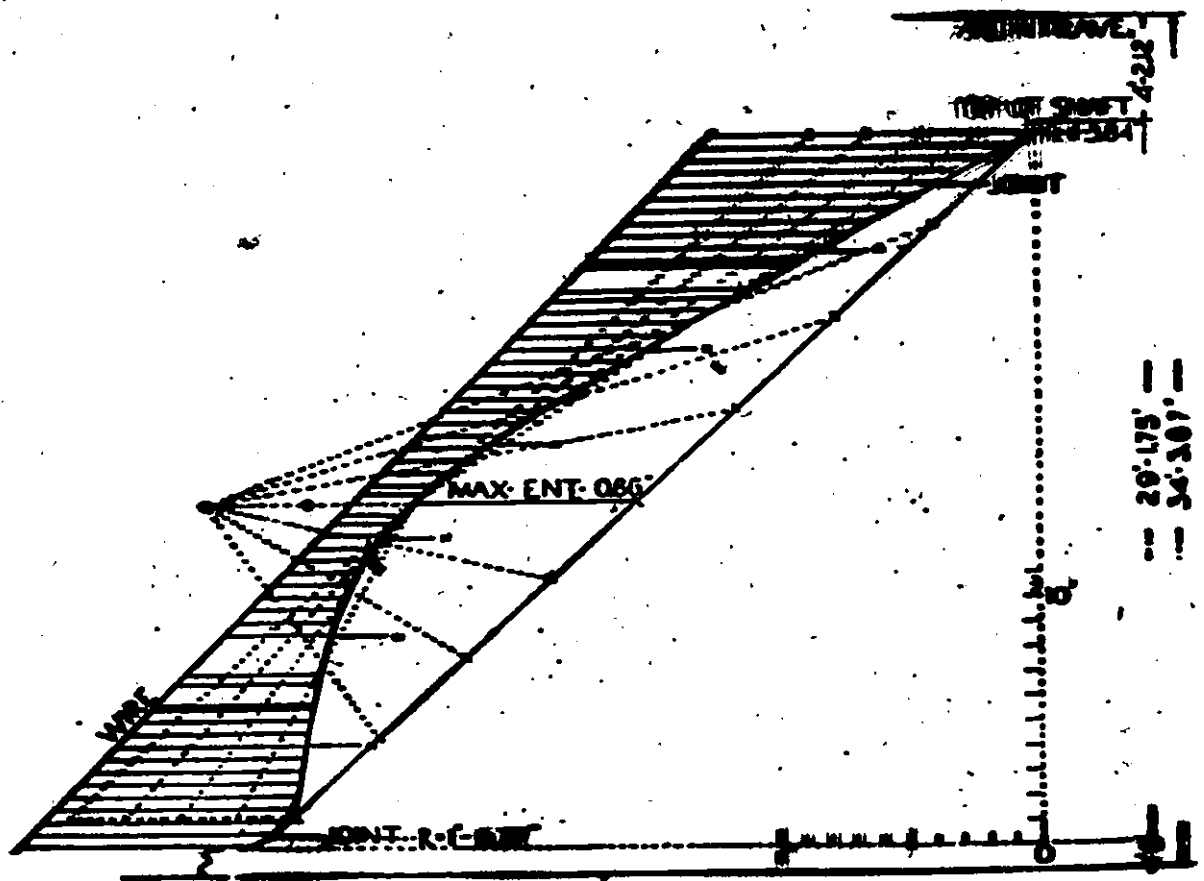


Fig. 14. Temple of Min Uruk.



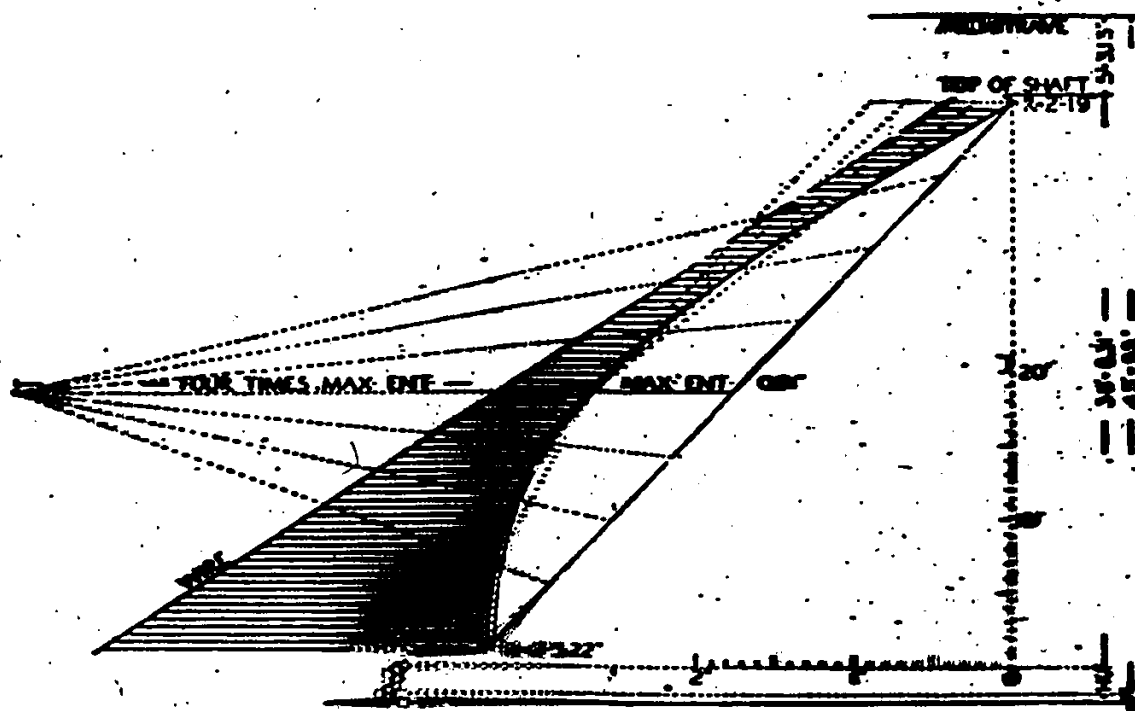


Fig. 17. Shaft, Cross Sec.

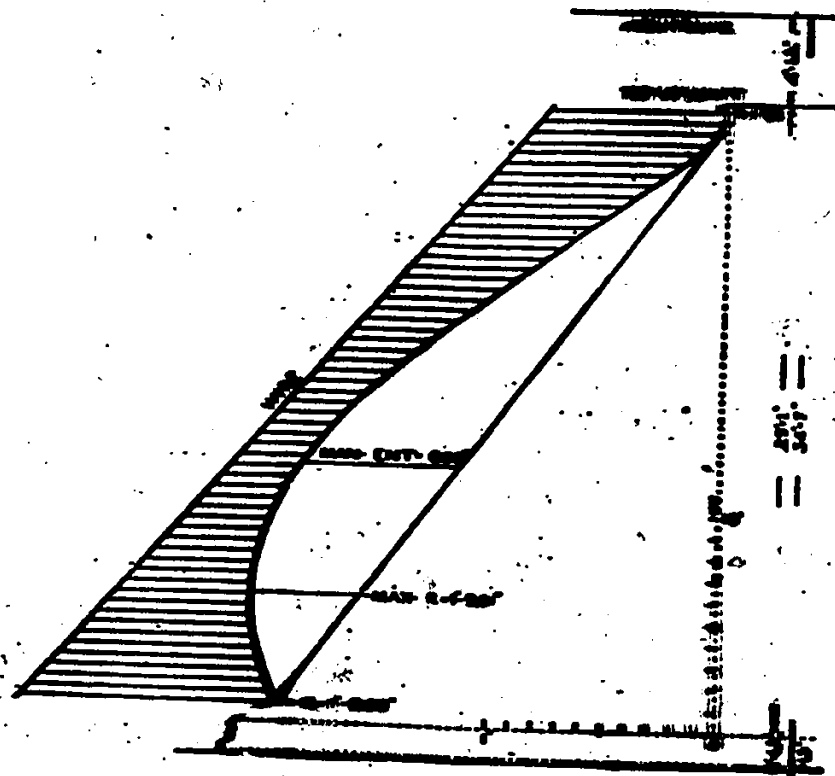


Fig. 10. Embankment, Side View.

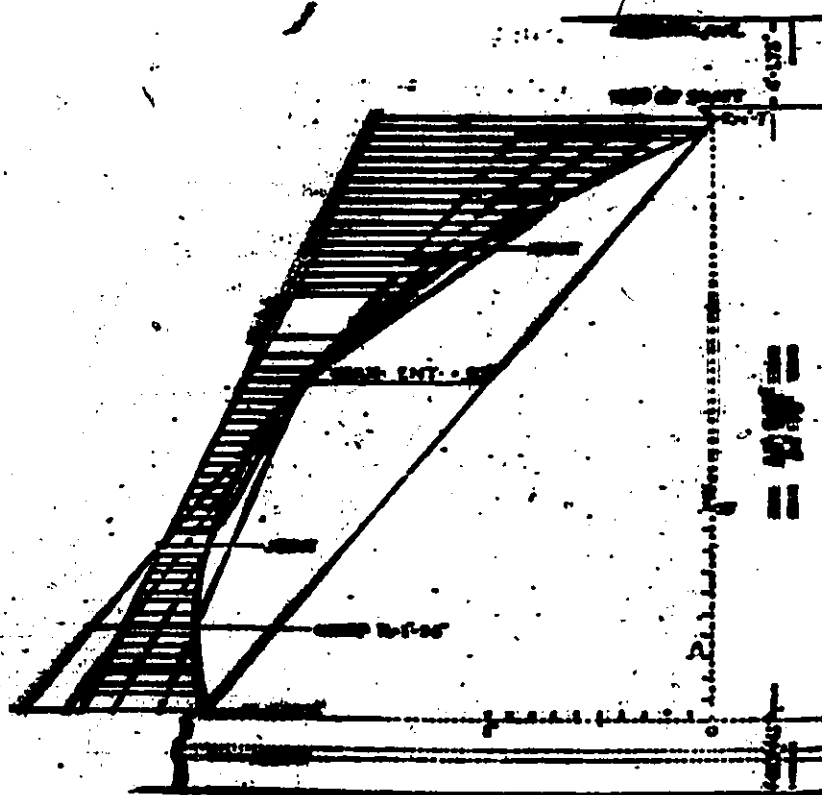


Fig. 12. Profile of Ocean.

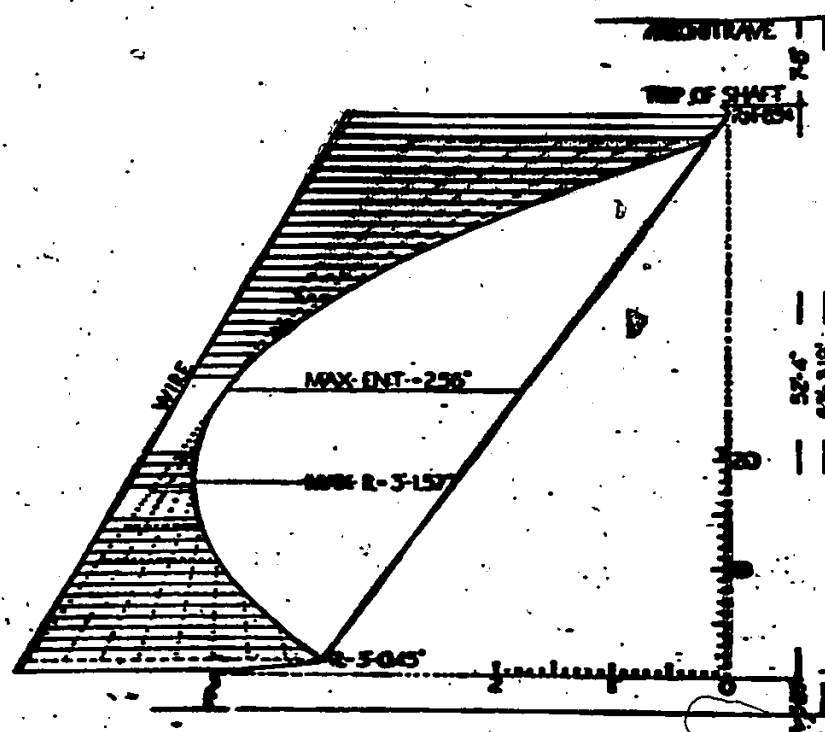


Fig. 22. Bottom of Casemate.

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