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by ROWLAND J. MAINSTONE

INTRODUCTION

The Theodosian church of St Sophia was destroyed on the first day of the great Nika rebellion of January 532. Its destruction provided Justinian with the pretext, at least, to rebuild it in a more durable and more magnificent form and presented his principal architects, Anthemius of Tralles and the elder Isidorus of Miletus, with an almost unprecedented opportunity. This opportunity they seized to the full. By a daring combination of structural forms never before attempted on such a scale, they created an interior whose superb spatial qualities still excite and amaze. A partial collapse in 558, little more than twenty years after the solemn dedication in December 537, showed that they had even been a little too daring and called for a partial reconstruction. But, after this had been completed by the younger Isidorus in 563, the rebuilt church acquired substantially its present form and remained for some 800 years the largest vaulted man-made structure in the world.

Today its domed silhouette (Fig.22a) is somewhat changed by the Turkish minarets added after it became a mosque in 1435 and, to a lesser extent, by further partial reconstructions and additions. Its earlier dominance of the city skyline is now challenged by the Imperial mosques and much of the Byzantine splendour of furnishings and mosaics has gone from the interior. This has been darkened also by the narrowing or blocking of numerous windows, especially by heavy buttresses piled against its lower flanks over many centuries. Nothing, though, can destroy the spatial experience of stepping from the narthex through the Imperial door into the nave. This great open space is, at the same time, both centred on the dome and given a marked eastward axial emphasis by two large semidomes, a narrower bema and a slightly projecting apse (Fig. 23). It expands also diagonally, at east and west, into four exedrae, and is embraced throughout its length, at north and south, by broad aisles and galleries half hidden behind open columnar screens (Fig.24).

The accounts of the rebuilding and the partial reconstruction of 558-63 by Procopius,[2] Agathius,[3] Malalas[4] and others and the descriptions of Procopius and Paul the Silentiary[5] are primary sources for mentally resurrecting the final Justinianic form of the church and tracing the processes by which it acquired this form. Other documents provide a starting point for identifying subsequent reconstructions and additions and subtracting them from the present structure. All these sources, even the most explicit, such as Agathius's account of the reconstruction of 558-63, admit, however, of a variety of interpretations. Only through the evidence of the building itself is it possible to choose between them.

Close examination of the building became feasible when it was secularized in 1935. In parallel with a systematic cleaning of the surviving mosaics by Thomas Whittemore, an architectural survey was initiated shortly afterwards by William Emerson and Robert Van Nice. Since the war this survey has been expanded, under the auspices of the Dumbarton Oaks Centre for Byzantine Studies, to cover, in meticulous detail, the whole of a vast and highly complex structure.[6] On the basis of the measurements and of observations of changes in materials and techniques, lacks of bond and other evidences of joins between successive phases of construction, it became possible some time ago to identify the precise extents of partial reconstructions of the dome and main semi-domes in 989-94 and 1346-53 and of that part of the reconstruction of 558-63 described in detail by Agathius. Most of the essential details of the system of arches that carries the main vaults were also established. The identifications have already been published[7] and they are illustrated, in part, in Fig. 25. For the present purpose it is sufficient to note here that only the reconstruction of the western sector of the dome and parts of the main west arch and semidome in 989-94 seems to have significantly changed the forms established in 563. An adequate picture of these forms is given by mentally substituting a replica of the corresponding reconstruction at the east for that at the west.

Here attention will be directed to some aspects of the initial conception and subsequent development up to 563 of the form of the Justinianic church that have hitherto remained obscure and that have, therefore, been a principal focus of recent investigations. These aspects have included the strengthening of the supports to the north and south of the dome that is hinted at, but nowhere clearly described, in the documents, and a reconstruction of the great tympana beneath the main north and south arches that was first thought to belong to this phase.[8] The aim has been to arrive at a clearer understanding of the problems that arose out of the practical realization of the initial architectural concept, of the manner in which they were tackled and of the changes that the initial concept underwent as it evolved into the definitive form of 563.

A full understanding is probably unattainable on the basis of the evidence that still survives. Even a partial one is much more elusive than in principle it should be, because of the virtual inaccessibility of much of the most revealing evidence in the building itself behind marble revetments, mosaics and other surface coverings. Inquiry has had to proceed very largely on the basis of inferences from careful correlations of surface measurements, reserving very limited explorations beneath the surface for crucial tests of these inferences. The conclusions that are presented must therefore remain, to some extent, tentative ones. They are, at least, rather less speculative than previous ones that have perforce had to rest too heavily on the documents alone.

ARCHITECTURAL ORIGINS

In very broad terms the basic concept of the design may be regarded, architecturally, as a fusion of, on the one hand, the pure centralized building hitherto chiefly associated with martyria and with imperial audience halls and the like and, on the other, the basilica which was at the time the generally favoured church form. If, as seems likely, the Theodosian church was an aisled and galleried basilica like St Demetrius in Salonika, this fusion may well have been prompted by the very special nature of St Sophia. It was not primarily a building for congregational worship, but rather a setting for some of the principal ceremonies of the Byzantine state – ceremonies in which the Emperor as Christ's temporal vicar played an equal role alongside the Patriarch as his spiritual representative. The most direct source still extant for the domical centralized form that was superimposed on the previous broad basilican plan was, undoubtedly, Justinian's earlier foundation of SS. Sergius and Bacchus[9] adjacent to the palace he occupied as emperor designate. Here the central domed space is similarly expanded by exedrae and apse and almost surrounded on two levels behind columnar screens by aisles and galleries. Only the further axial expansion of the central space by large semidomes and the vastly greater scale of St Sophia are lacking.

Granted these origins of the basic concept, they nevertheless provided Anthemius and Isidorus with no more than a starting point. Their real difficulties must have begun with the development of the concept and its practical realization in all its details. In tackling them they were spurred on and encouraged, no doubt, by Justinian's enthusiasm, but they were possibly given little chance to exercise the caution that would today be considered wise in such an undertaking.

STRUCTURAL PROBLEMS

We can form some idea of the magnitude of the problems they faced on the structural plane if we remember that the nearest precedents we know of on a comparable scale for what they attempted were much earlier, distant and very different buildings like, on the one hand, the Roman Pantheon and, on the other, the basilica of Maxentius and the tepidaria of some of the Roman imperial baths.

A more revealing picture is given by a consideration (in terms of modern structural theory) of the principal structural actions brought into play in carrying out a decision to vault the entire nave without intermediate supports, carrying the whole vaulting system of dome, semidomes and sustaining arches only on massive piers at a few points on the perimeter.

A masonry arch may be likened to an inverted chain. A frictionless chain hung from two points automatically assumes a catenary form which brings the tensions transmitted from link to link into equilibrium with the weights of the links. The inversion of this catenary curve of chain tensions gives the thrust line for an arch whose voussoirs are similarly weighted. Provided that its supports remain immovable and exert appropriate reactions to the end thrusts, the arch will be stable if this thrust line can be contained everywhere within its thickness without being sufficiently oblique, at any point, to the abutting faces of the voussoirs to cause slipping. This, of course, places some restriction on the curves that can safely be adopted for extrados and intrados for a particular thickness and loading.

A doubly curved shell like a dome can be considered as composed of a series of orange-slice arches with a common keystone at the crown. Ideally the curves of these arches can, however, safely vary between much wider limits for a given thickness and loading, or alternatively the thickness can be much reduced for a given curve and loading, because the shell can also be considered as a series of horizontal rings. In the upper part these horizontal rings will also act in compression like continuous horizontal arches. Lower down they may, if able to resist tension, act as tensile hoops (Fig. 27a, top centre). In doing so they will be capable, as it were, of pushing or pulling the thrusts in the vertical arches so that they follow the curve of these arches whatever this is. Another important consequence of this, provided again that the supports do not move, is that the thrusts at the base can be made to act tangentially to the surface of the shell. If, for instance, the shell is a full hemisphere, they will be vertical: there will be no horizontal thrust at all. For a spherical shell that is less than a full hemisphere though, there will inevitably be some horizontal thrust which must be absorbed by the supports.

The corresponding action of a semidome can be visualized if the full dome is notionally sliced on a vertical plane through its crown. The action will be similar (Fig. 27a, top left and right), provided that the pushes and pulls in the horizontal rings that have been cut are balanced in some other way along the cut edge.

Today the dome and greater and lesser semidomes of St Sophia could be constructed so that they behaved almost in this manner. They could all then be made very thin indeed, though some thickening would be necessary at the free edges of the semidomes. The chief requirement would be adequate tensile reinforcement of these free edges and of all the shells below the level at which the stresses in the horizontal rings become tensile. The semidomes, having vertical springings, would then exert no horizontal thrusts there. Some horizontal thrust would be exerted by the dome since this is, and always was, less than a full hemisphere, but that thrust could be absorbed by a further tie at the base. The only thrusts unavoidably reaching the level of the springs of the sustaining arches would be those generated by the arches themselves. Even these could be contained within the superstructure by means of ties across the springs of the arches. Buttresses could then be dispensed with for simple gravity loading.

In a project of this magnitude in sixth-century Constantinople, however, completion within a mere six years was possible only by using materials and skills that could then be readily assembled. This meant constructing both dome and semidomes of bricks and mortar without tensile hoop reinforcement. All the semidomes, and probably the original dome also (like the present one), were, moreover, perforated by window openings in their lower parts. Their structural actions would, therefore, approximate much more to that of rings of orange-slice arches than to that of the ideal shells just considered. Stability would call for the much increased thicknesses appropriate to such arches, and large horizontal thrusts would inevitably be exerted radially around the bases.

In principle the thrusts at the bases could have been contained there by circumferential ties. Taking, for instance, the figure most frequently quoted in the sources for the amount by which the height of the original dome fell short of that of the present one[10] and assuming that its average thickness was unchanged in the sixth-century reconstruction, the horizontal thrust exerted at its base would have been almost 6,000lb per foot of circumference. This could have been contained by a circumferential tie with a yield strength somewhat in excess of 300,000lb.

It is most unlikely, though, that effective ties of this order of strength could have been made at the time, and, in their absence, all the thrusts developed by the vaults would be transmitted to the supporting arches and piers. However strong these were, they would yield to some extent in taking up the loads. The main arches abutted by the large semidomes at east and west would initially be bent inwards by the crown thrusts of the semidomes. Subsequently, when the dome was constructed, these crown thrusts would be balanced by the opposing thrusts of the dome itself, but the arches would then bend back to a lesser extent because their mortar would, in the meantime, have stiffened considerably. At north and south the main lateral arches would, similarly, be bent outwards by the dome thrusts and, in acting as horizontal arches in resisting these thrusts, they would, incidentally, thrust to east and west on their supporting piers as well as to north and south. The piers, in turn, subject also to the thrusts developed by the arches in carrying the vertical loads, would be pushed apart. As a result all the vaults would spread at their bases, the radial cracking into orange-slice arches would extend, and the resultant pattern of principal stresses would resemble that shown in the lower part of Fig. 27a. Estimates based on measurements of the present structure, but making some allowance for the changes it has undergone since 537, suggest that a thrust of about 1,000,000lb in all would act to east or west on each pair of main and secondary piers A and B (Figs. 24 & 25) and that a thrust of similar magnitude would act to north or south on each main pier A. Since that part of the thrusts to east and west that is due to the dome is effectively carried down to the level of the springs of the semidomes it is, however, potentially less damaging than the corresponding part of the thrusts to north and south which acts on the main piers effectively at the level of the dome cornice. Whether or not these thrusts could be resisted by the piers without excessive movement leading to collapse would depend chiefly on their detailed proportioning in relation to their heights and manner of construction.

CONSTRUCTION

Qualitatively Anthemius and Isidorus must have been aware, from observation of existing buildings, that large arches and vaults cracked and distorted and pushed aside their supports in this manner. Today we can see evidence of this in many Roman structures that have not been too heavily restored. There are excellent examples of radial cracking of domes due to circumferential tensions and thrusting apart of the supports in the Pantheon and some of the remains of the baths of Trajan; there is also a perfect example, closely paralleling what is seen in St Sophia, of the thrusting action of a semidome on buttress piers in the temple of Venus and Rome. Similar evidence must have been visible in some of the earlier buildings of Constantinople: indeed SS. Sergius and Bacchus today exhibits much the same distortions in its galleries as can be seen in St Sophia, and it is almost certain that the pronounced outward tilts of its piers and columns, for instance, were clearly apparent when St Sophia was built. The general effect of earthquakes, giving as it were brief sideways pushes to the normal direction of gravity and calling therefore for some ties or buttresses even in the absence of vault thrusts, would also be known.

Evidence of this awareness is seen in numerous details of the design such as the greater stiffness given to the main north and south arches as compared with those at east and west; the backing-up of the main piers by buttress piers C at north and south (Figs. 24 & 25); the obvious care taken in the construction of the piers; and the widespread incorporation of timber and iron ties, particularly in the vaulting systems of the aisles and galleries. The construction as a whole seems to be characterized by the sort of careful workmanship and systematic use of different materials according to structural function that is seen in the Roman Colosseum and a few other major structures of Justinian's time such as the church of St John at Ephesus and Basilica B at Philippi. It therefore contrasts markedly with the rather slipshod construction typical of earlier buildings in the city like the Theodosian walls and the church of St John Studios. The main and secondary piers up to the level of the upper cornice (from which the main arches and the semidomes spring) and the lower parts of the buttress piers are, for instance, constructed of large blocks of greenstone or limestone carefully fitted together with thin joints, usually of mortar but sometimes of lead to give, as Paul the Silentiary noted,[11] a more even distribution of pressure. The use of brickwork for all vaults and associated arches merely followed that tradition of the eastern empire exemplified by buildings such as the Rotunda of Galerius in Salonika and the Red Basilica in Pergamon. The large quantities of brick dust in the mortar would, however, give it qualities very similar to those of the natural pozzuolanic mortars used in Roman concrete. All the cornices (or string courses) are formed of large marble blocks, almost certainly cramped together beneath the masonry they carry as well as, more evidently, on their free surfaces.

The principal problems would lie in the quantitative application of what had been observed elsewhere, guided only by the very limited further insights offered by the science of the day, in which both architects were acknowledged experts. In terms of the design adopted they would involve assessment of the effectiveness of such ties as could be provided; of minimal cross-sections of piers; of the amount of interconnection needed between main piers, and buttress piers to link them effectively in resisting thrusts; and, most difficult of all perhaps, of the effect of rate of construction on development of the strength of masonry and magnitudes of its deformations under load.

FAILURES AND REMEDIAL ACTIONS

The partial collapse in May 558 showed that these problems had not been fully solved. The collapse is recorded as having been preceded by a severe earthquake in December 557 and to have taken place when the dome was already under repair.[12] It involved part of the eastern arch and parts of the adjacent semidome and the dome.

Earthquake loading can cause the collapse of an arch, if it is slender enough, without any yielding of its supports. In the present case, though, it can easily be demonstrated that, if its supports remained fixed, each of the main arches of

St Sophia was quite deep enough to withstand the worst conceivable earthquake. The collapse that occurred could only be the result of considerable yielding of the main piers and consequent spreading of the base of the arch. Yielding to this extent was in turn possible only if the interconnections with the buttress piers failed.

At ground and gallery levels the connections are made by brick barrel vaults spanning directly from pier to buttress (*a,a* Fig. 25), but these are now underpinned and stiffened by pairs of stone arches carried on unbonded stone projections from pier and buttress (*b,b,b,b* Fig. 25). Above the gallery roof there are pairs of brick segmental arches (*c,c* Fig. 25). These carry parallel brick walls spanned at two levels by barrel vaults running from north to south (*d,d* Fig. 25). The walls are unbonded to the backs of the pendentives (i.e. to the upward extensions of the main piers), but they are continuous with the east and west walls of the stairway-tower extensions of the buttress piers. The lacks of bond, as well as other details, indicate that all the interconnections except for the barrel vaults *a,a* could be additions to the original design and, if so, presumably made only after signs of failure had become apparent.

The documents suggest the possibility of additions both during initial construction and immediately following the earthquake or the subsequent collapse. Procopius,[13] for instance, refers specifically to a threatened collapse even while the main eastern arch was being built and the Silentiary[14] echoes this reference in saying that Anthemius 'gave to the walls strength to resist the pushing arches, which were like active demons', while both Theophanes[15] and Cedrenus [16] make enigmatic references to the erection of 'new piers to receive the dome' in their accounts of the reconstruction of 558-63.

Before considering the possibilities further, it is desirable to review briefly the extent of the reconstruction of 558-63 as described by Agathius and as more precisely established by previous investigations of the present structure.[17] It included (1) the rebuilding of the fallen parts of the eastern arch and semidome, probably without any significant change in form; (2) the 'piecing-out' or partial reconstruction of the upper facing arches at north and south (*e,e* Fig. 25), and partial reconstructions of the pendentives, to reduce the north-south spread of the base of the dome; (3) filling out of the corners of the dome base to give it its present square exterior form; and (4) the entire rebuilding of the dome to its present raised profile. Though the younger Isidorus would have been unable to estimate precisely the effect of this raising of the dome profile, it would have reduced the horizontal thrust by about 30 per cent, increasing the weight by almost the same proportion if average thickness was unchanged.

If it is assumed that the 'piecing-out' of the facing arches brought their crowns back into the same vertical planes as their springings, the extent to which they now again lean out gives an approximate measure of the extent to which the main piers have yielded since 563. In relation to their total present inclinations from the vertical, the subsequent movement has, on this basis, been about 40 per cent, that up to 558 being about 60 per cent.

In general it can also be assumed that each of the elements of the interconnections between the main and buttress piers was, when constructed, set out with its unengaged upright faces vertical and with the soffit of each arch or vault a simple circular arc, the only exception being the segmental arches *c,c* for which, with the heights adopted for the crowns, the latter was not practicable merely by swinging a card around a fixed centre. Making this further assumption and comparing relative present inclinations and distortions, the sequence of construction can now be established with considerable certainty on the basis of recent measurements. The segmental arches and the walls they carry clearly belong to the original construction, though it does appear that they were built rather hurriedly only as the 'active demons' of the pushing arches were making themselves felt. They may well, therefore, be additions to the original design in their upper parts at least. The bracing arches and the projections which carry them, *d,d,* are, on the other hand, now equally clearly subsequent additions, made only when about 25 per cent of the present pier tilts had already occurred and when the shear failures of the barrel vaults *a,a* and of the segmental arches and walls above the gallery roof (Fig.26)[18] were already very obvious. It is more difficult to date them precisely, but they were almost certainly built well before the earthquake of 557 and the subsequent collapse. The repairs in progress at the time of the collapse probably consisted chiefly of the filling of gaping cracks in the main vaults and arches and in the insertion of fresh cramps and ties on the cornices, of which there is evidence today particularly on the upper cornice from which the main arches spring. The fillings of openings in the main piers at gallery level, marked *f* and *g* in Fig.24 but omitted from Fig.25, are much later and they contribute very little, in any case, to the resistances offered to the thrusts to north and south that led to the collapse.

It is implicit in this sequence of modifications to the design before 557 that the earthquake of that year was not the primary cause of the collapse. Together with earlier earthquakes[19] in 542, 543, 546, 548, 554 and 555 it merely sought out an inherent weakness. As in 989 and 1346, it probably accelerated the collapse mainly by momentarily reducing the frictional resistances that would normally oppose the slipping and dropping out of the crown of the arch that must have occurred. Confirmation that static thrusts of the main vaulting system were the primary causes of failure is provided both by the remarkable symmetry of the present tilts and other deformations in relation to the resistances opposing them and by estimates of shearing actions on critical sections through interconnections between piers. The shearing action on the heavily hatched section in Fig.25 when construction was completed in 537 would, for instance, have been well within the limits at which initial failure might be expected.

OTHER EARLY CHANGES IN THE DESIGN

What other changes took place in the design as the detailed implications of the basic concept were worked out and as construction proceeded? In attempting to answer this, one is on much less sure ground. Previous commentators have agreed in suggesting a more or less major change in the form of the filling of the spaces beneath the main north and south arches, while disagreeing as to its precise nature and its date. Procopius unequivocally states that the upper parts of the fillings, as originally built, had to be removed during or shortly after the construction of the arches and replaced later.[20] But he mentions here no change in their form. The suggestions of such a change are based mostly on his earlier description of the interior,[21] presumably after the replacement, and an apparent inconsistency between this and what we should see today if the late narrowings of the window arches of the present tympana were removed (Fig. 27b). The description has generally been thought to refer to large open windows similar to the present west window (Fig. 22b) in place of one or both of the present ranges of smaller windows.

The evidence of the building itself now conclusively points to a later and much more extensive reconstruction than that referred to by Procopius. Not only the entire tympana but also the gallery colonnades immediately beneath them have been rebuilt.[22] The present inclinations and crack widths both suggest that this was done when the tilts of the main piers to north and south had reached about 60 per cent of their present values, as at the time of the reconstruction of 558-63. This alone, though, is inconclusive, since we are here concerned with fillings and not with elements subject directly to primary structural actions. Confirmation of the fact of the reconstruction and a better indication of its date have been obtained by means of limited tests beneath the surface at points where the joins between original and reconstructed masonry were expected. The date now appears to be a ninth-century one and the reconstruction to be, in fact, part of that referred to in the inscriptions which once filled the spaces above the heads of the ranges of windows.[23]

The reconstruction is therefore strictly outside the scope of this paper and the observations are relevant more for the light they have thrown on the previous form of the fillings. Up to the heads of the lower ranges of windows these can have differed little from the original form of the present tympana except that the rows of shallow niches below the windows appear to have been ninth-century innovations to receive the standing mosaic figures of bishops executed shortly afterwards.[24] Suggestions that large open windows ever filled the whole spaces beneath the arches as at the west can, therefore, be rejected, as can Lethaby's suggestion [25] (followed by Antoniades[26] and Gurlitt[27]) that the fillings originally stood much farther back from the nave. The possibility that a smaller single window took the place of the present upper range on each side remains, however, and this arrangement would certainly be more consistent with the Silentiary's reference to 'eight windows' in each wall.[28]

One further detail of the present structure may be relevant here. This is the lack of correspondence between (1) the flat pilasters (marked *h,h,* in Figs. 24 & 25) which project from the main piers at gallery level to receive the ends of the arcades carrying the tympana and (2) the arcades themselves – an awkwardness which results in the sudden and seemingly unpremeditated termination of the excess width of each pilaster just above the head of the arcade (Fig. 26).[29] The pilasters are, in fact, of the same width as those at ground level, where they do answer correctly to the greater width of the more massive ground arcades.

This detail does strongly suggest an even more momentous change in design than those previously considered, but one that was made at a fairly early stage of construction and probably did not involve any demolition and rebuilding. The implication is that the original intention was, as in SS. Sergius and Bacchus, to follow the classical precedent of constructing the gallery colonnades with each column answering directly to the one below and similar to it in scale to give the same width of impost above the capital. Instead, but only when construction of the main piers had reached a considerable height above the gallery floor, the design was slightly scaled down and the very unclassical and unstructural relationship of the upper and lower colonnades introduced.

Looking at the central bay at the west end (Fig. 22b), we do see a completely classical treatment right up to the very Roman form of the great west window. The initial intention may well have been to treat in a similar way the whole of the bays enclosed by the main piers and the north and south arches and to echo this treatment in the exedrae up to the upper cornice level. In place of the present tympana there would then indeed have been the huge open windows suggested by some commentators.

If so, it is largely to this change in design that we owe, among other things, the most characteristic quality of the architectural expression of the interior – its characteristic dematerialization of all structural mass, the very antithesis of a clearly expressed structural articulation of the forms. It left the spatial organization unaltered but profoundly affected its impact on the observer.

The more that is learned about the history of the church between 532 and 563, the more it seems desirable to regard this whole period as one of continual development of the design, sometimes in matters only of critical detail but at others in matters of much greater moment.

Such progressive development of the design of a major building is, of course, well documented in a number of more recent instances,[30] and there is all the more reason to expect it here because of the hurried start of the reconstruction after the rebellion had been quelled. The creative genius of the architects would be continually challenged by the difficulties that arose and is to be judged largely by the manner in which they reacted to them.

Genius of the order that they displayed is rare: the opportunity to deploy it on this scale probably rarer still. Well might Justinian exclaim at the solemn dedication: 'Glory to God who has thought me worthy to finish this work. Solomon, I have outdone you.'

NOTES

1 This paper is a slight expansion of part of the Annual Lecture delivered to the Society in January 1968. It is based on a continuing study of the church sponsored by the Dumbarton Oaks Centre for Byzantine Studies, Harvard University, and thanks are due to Dumbarton Oaks for permission to publish it; to Mr Robert L. Van Nice, whose measurements have been the essential starting point and whose intimate knowledge of the building has been made freely available throughout; to Professor Cyril Mango for translations of some of the documents; and to the Turkish authorities, particularly Bay Feridun Dirimtekin, Director of the Aya Sofya Museum, for their unfailing co-operation.

2 Procopius, *De Aedificiis*, I, i, 20-78 (Loeb ed., 1940), pp. 8-33.

3 Agathius, *Historiae*, Bonn Corpus, i (1828), p. 296 (translations in the papers by Conant and Mainstone cited below in note 7).

4 Malalas, *Chronographia*, Bonn Corpus xv (1831), pp. 489-495.

5 Silentiarius, *Descriptio Sanctae Sophiae*, translation in W. R. Lethaby & H. S. Swainson, *The Church of Sancta Sophia, Constantinople* (1894), pp. 35-52.

6 The survey is in course of publication by Dumbarton Oaks. A first instalment of plates has appeared: Robert L. Van Nice, 'Saint Sophia in Istanbul: an architectural survey', 1966. A second instalment of plates and a text volume by Mr Van Nice, Professor Cyril Mango and the present writer will follow.

7 See, especially, W. Emerson & R. L. Van Nice, 'Haghia Sophia, Istanbul: Preliminary report of a recent examination of the structure', *American Jnl. of Archaeology*, xlvii (1943), pp. 403-436; K. J. Conant, 'The first dome of St Sophia and its rebuilding', *The Bulletin of the Byzantine Institute*, i (1945), pp. 71-78; R. L. Van Nice, 'The structure of St Sophia', *Architectural Forum*, cxviii (1963), pp. 131-139; and R. J. Mainstone, 'The structure of the church of St Sophia, Istanbul', *Trans. of the Newcomen Society*, xxxviii (1965-66), pp. 23-49.
8 P. A. Underwood & E. J. W. Hawkins, 'The mosaics of Hagia Sophia at Istanbul: the portrait of the Emperor Alexander', *Dumbarton Oaks Papers*, No. 15 (1961), pp. 189-217.
9 The best recent description of this church is P. Sanpaolesi, 'La chiesa dei SS. Sergio e Bacco a Constantinopoli', *Rivista dell' Istituto Nazionale d'Archeologia e Storia dell' Arte*, n.s. x (1961), pp. 116-180.
10 A figure of 20ft has been assumed as given by Malalas, though Theophanes and Cedrenus change this, in fact, to 'more than 20ft'. In a later reference Malalas gives 30ft, while Zonarus gives 25ft.
11 Lethaby & Swainson, *op.cit.*, p. 41.
12 Malalas, *op.cit.*, p. 489; Theophanes, *Chronographia*, ed. de Boor, p. 232; Cedrenus, *Synopsis Historiae*, Bonn Corpus xxxiv (1838), p. 676.
13 Procopius, *op.cit.*, I, i, 68-73.
14 Lethaby & Swainson, *op.cit.*, p. 36.
15 Theophanes, *loc.cit.*
16 Cedrenus, *loc.cit.*
17 Emerson & Van Nice, *loc.cit.*; Conant, *loc.cit.*; Mainstone, *loc.cit.*
18 See Mainstone, *op.cit.*, pp. 33-34, for more detailed drawings of typical examples of these failures.
19 The most useful recent catalogues of earthquarkes are Glanville Downey, 'Earthquakes at Constantinople and vicinity, AD 342-1454', *Speculum*, xxx (1955), pp. 596-600, citing documentary sources; and K. Ergin, U. Güclü & ve Z. Uz, *A catalogue of earthquakes for Turkey and the surrounding area AD 11-1964* (1967), including instrumental data for the more recent shocks. I am indebted to Professors Said Kuran and Mufit Yorulmaz of the Technical University, Istanbul, for a copy of the latter and an abstract from it of shocks in the neighbourhood of Istanbul.
20 Procopius, *op.cit.*, I, i, 74-78.
21 Procopius, *op.cit.*, I, i, 40.
22 A full account of the evidence was due to appear in *Dumbarton Oaks Papers*, No. 23, but has now been postponed to No. 24 [1970].
23 C. Mango, 'Materials for the study of the mosaics of St Sophia at Istanbul', *Dumbarton Oaks Studies*, viii (1962), pp. 63-66.
24 C. Mango, *op.cit.*, pp. 49-57.
25 Lethaby & Swainson, *op.cit.*, pp. 210-215.
26 E. M. Antoniades, *Ekphrasis tēs Hagias Sōphias* (1907-09).
27 C. Gurlitt, *Die Baukunst Konstantiopels* (1907-13).
28 Lethaby & Swainson, *op.cit.*, p. 43.
29 See Underwood & Hawkins, *loc.cit.*, for more detailed illustrations.
30 The cathedrals of Milan and Florence, St Peter's and St Paul's are well-known examples. The Paris Pantheon is, in some respects, a closer parallel.

Fig. 22a *St Sophia: exterior from the south* (author)

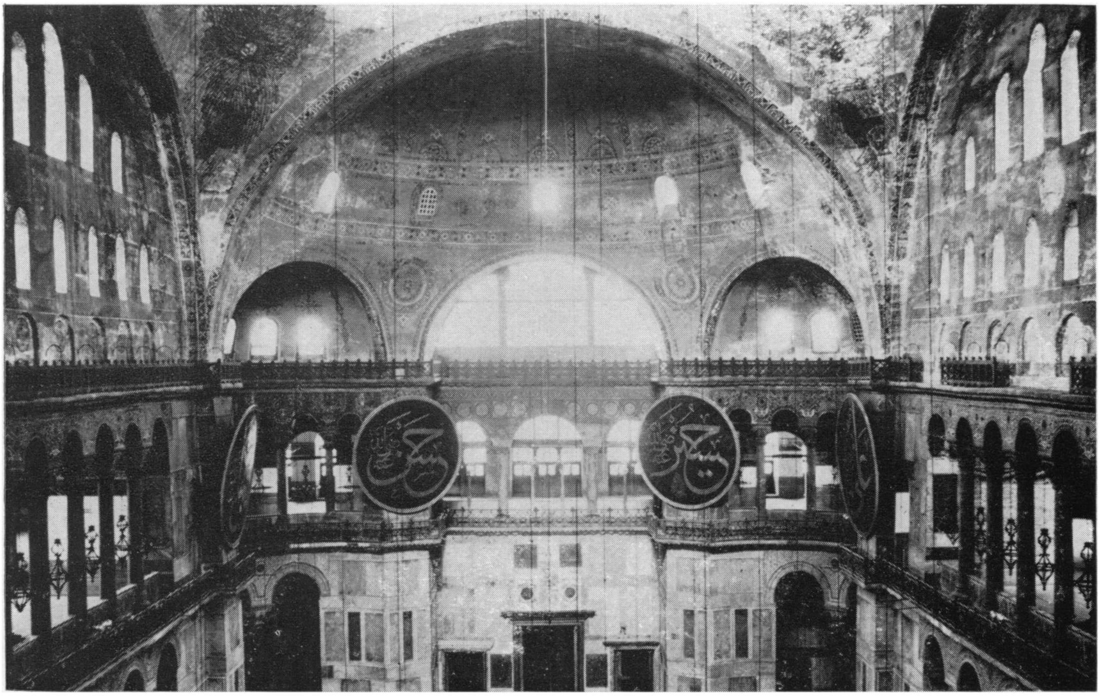

Fig. 22b *St Sophia: interior looking west* (author)

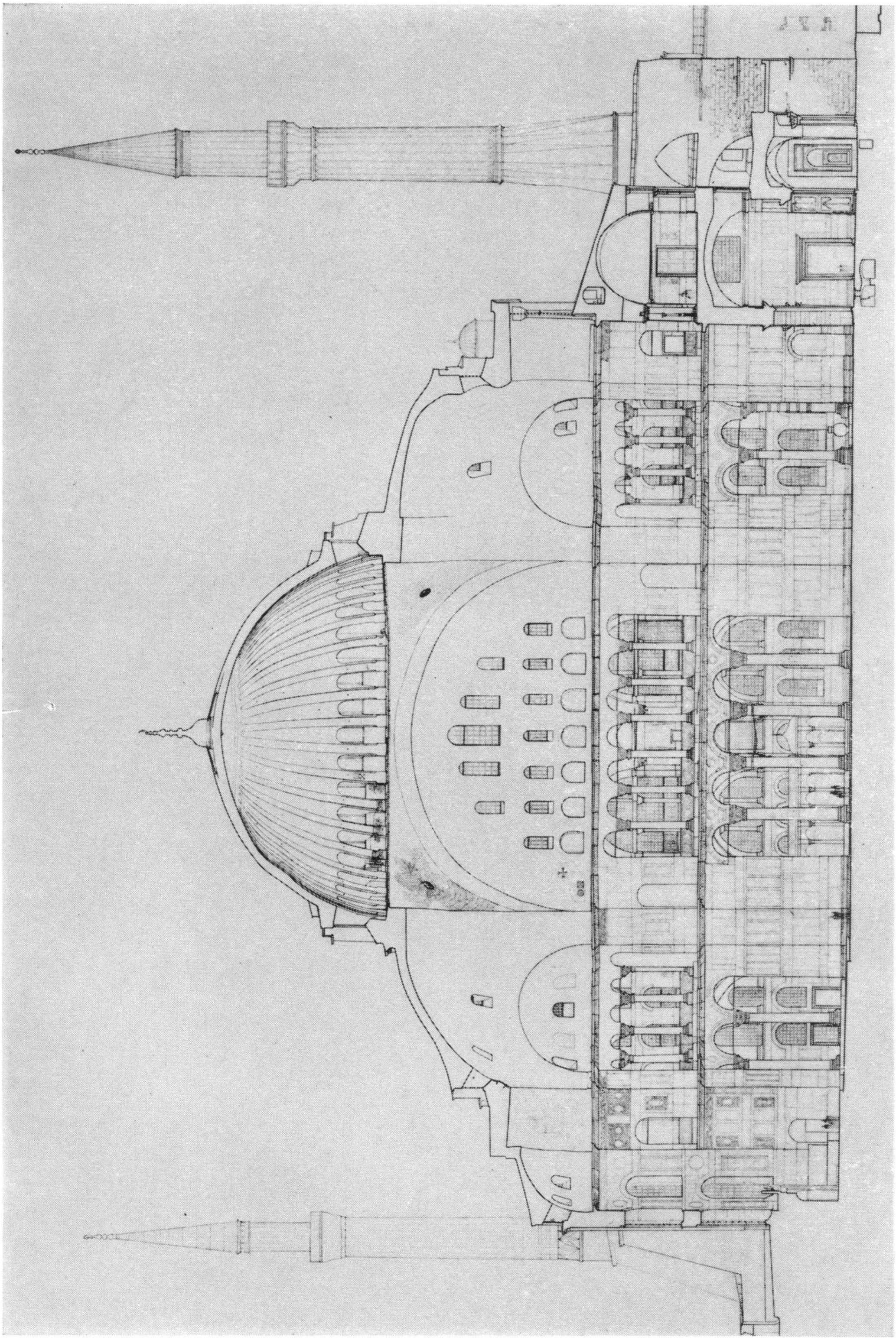

Fig. 23 *St Sophia: longitudinal section looking south* (R. L. Van Nice & Dumbarton Oaks)

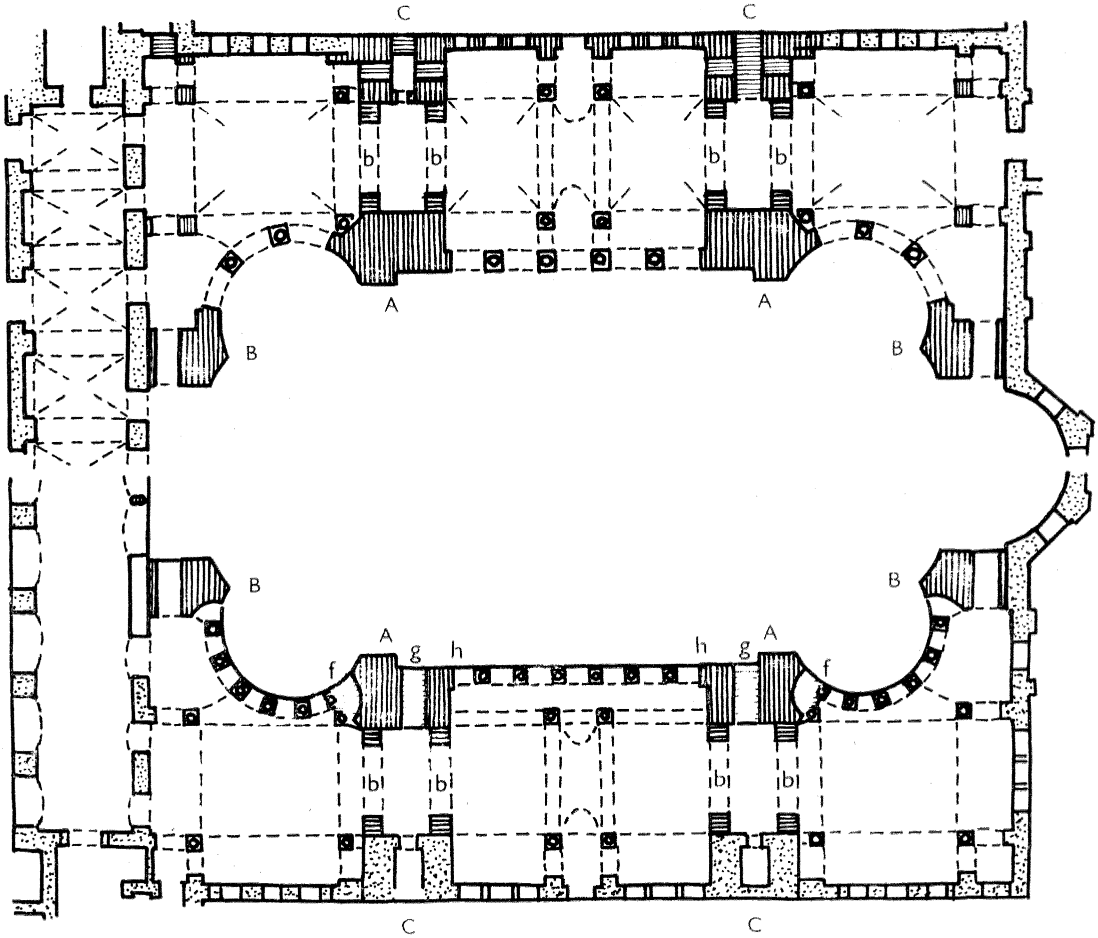

Fig. 24 *St Sophia: half plans at ground level (above); and gallery level (below). Stippled areas represent brickwork and hatched areas stone, though some of these indications of materials and some of the lacks of bond also shown have not been directly tested and must be considered as tentative. Vertical hatching represents the initial phase of the sixth-century reconstruction and horizontal hatching the subsequent additions to this, sixth-century and later additions being distinguished by heavy and lighter hatching respectively* (author).

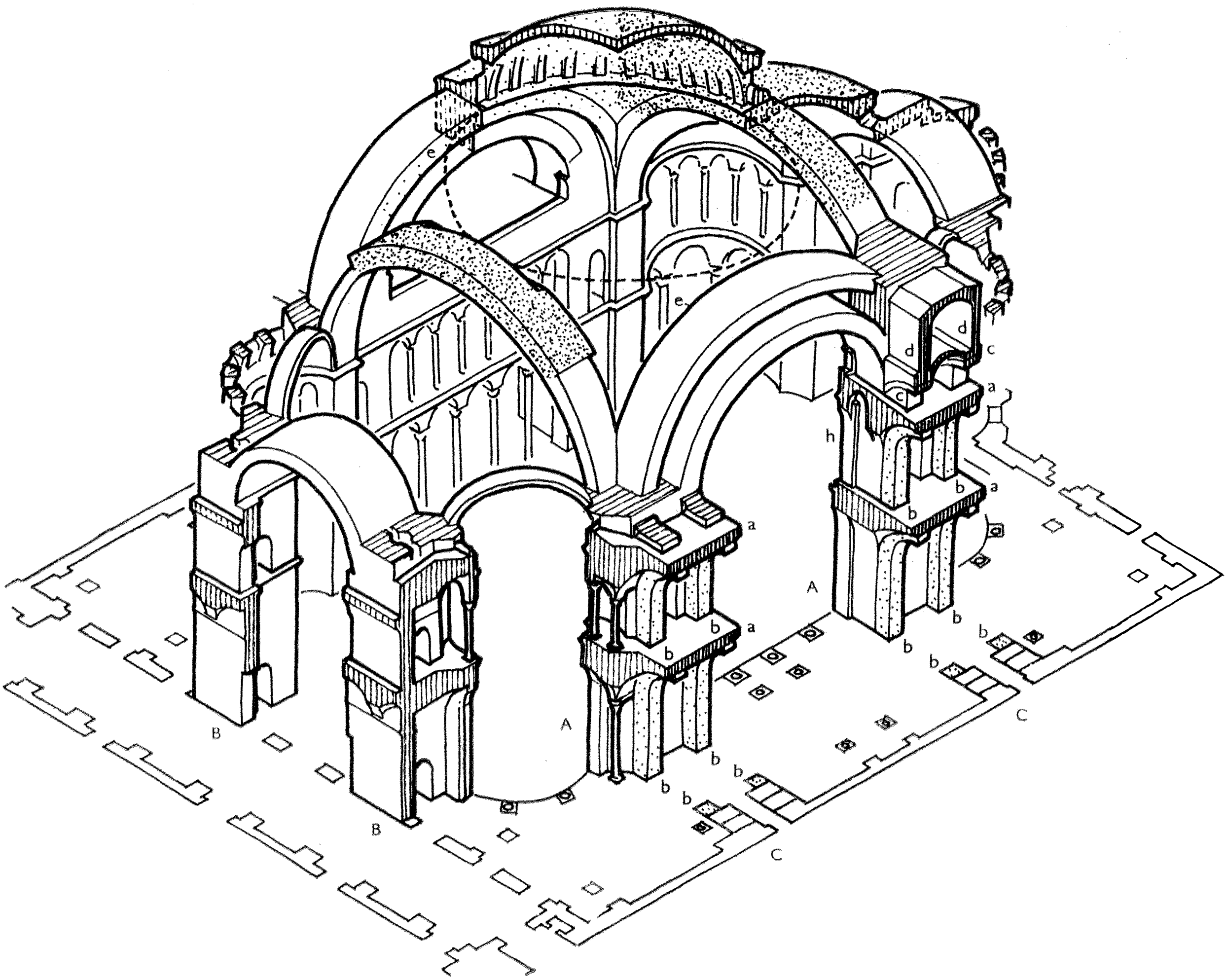

Fig. 25 *St Sophia: cut-away isometric sketch of the basic structural system seen from the south-west. Lightly stippled elements are sixth-century additions to or (in the case of part of the dome) modifications of the original form. Heavily stippled elements are later reconstructions, tenth-century at the west and fourteenth-century at the east* (author).

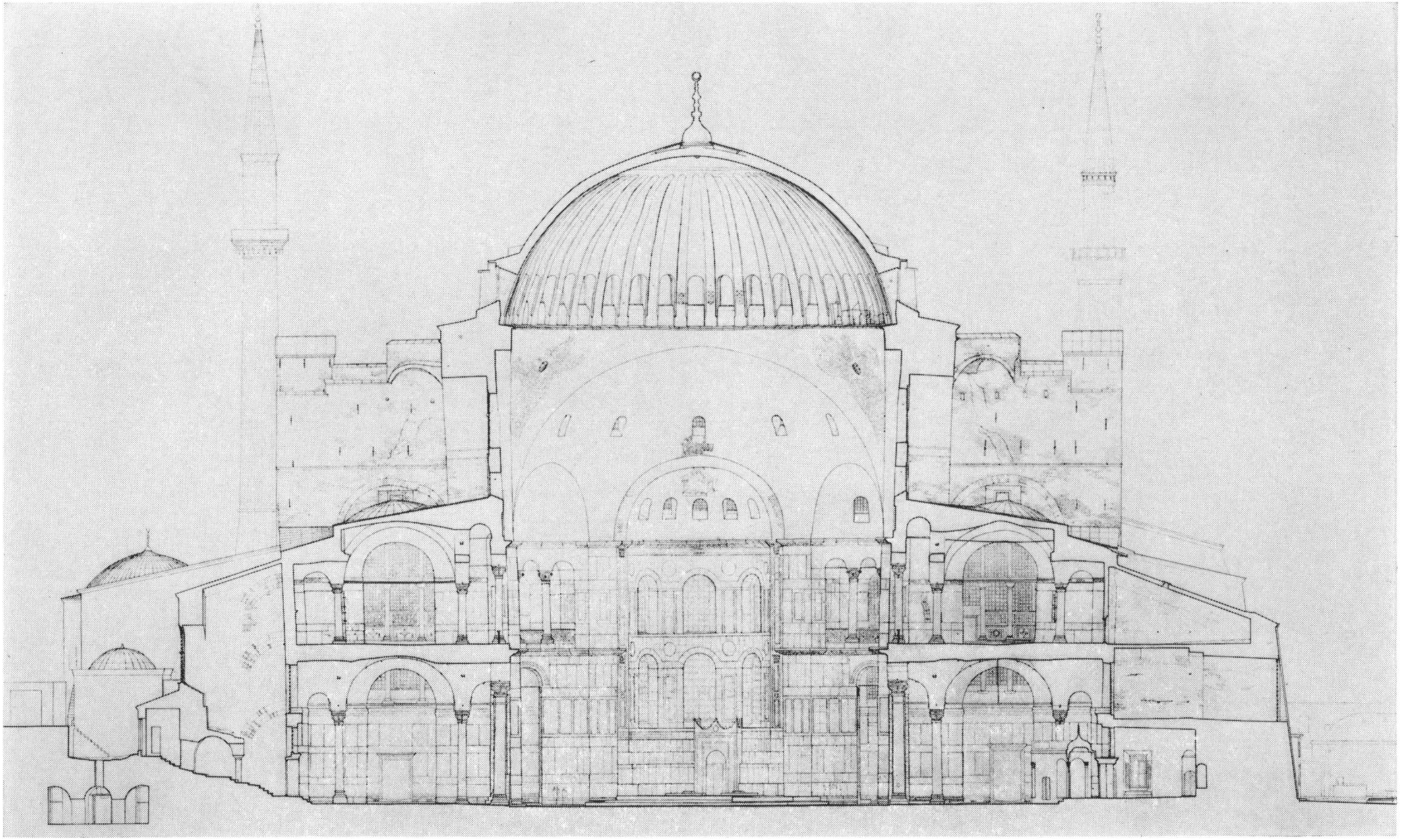

Fig. 26 *St Sophia: transverse section looking east* (R. L. Van Nice & Dumbarton Oaks)

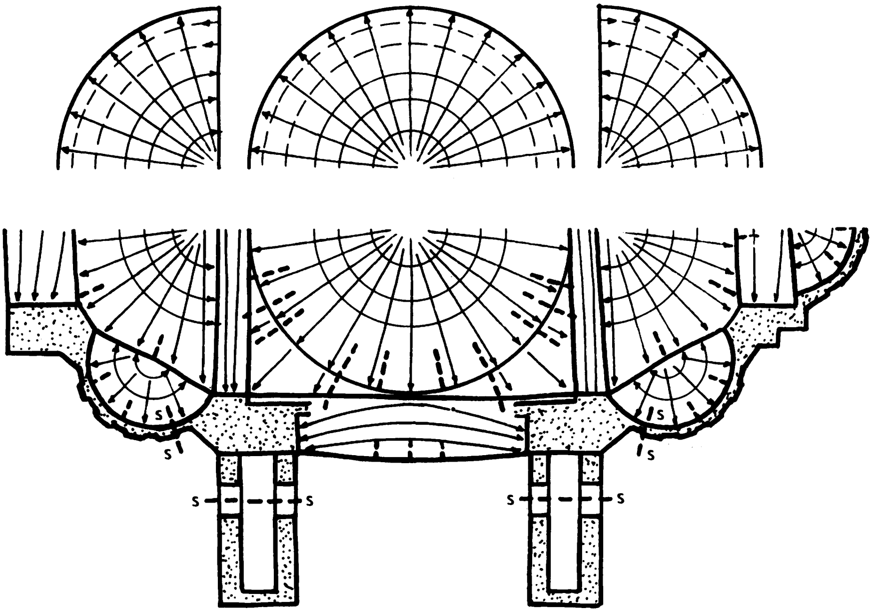

Fig. 27a *St Sophia: part plans of the main superstructure Above are shown ideal distributions of principal stresses in the dome and main semidomes. Below are the probable actual distributions. Light continuous lines represent compressive principal stresses. Light broken lines represent tensile principal stresses. Heavier broken lines represent major tensile cracks or (at the sections marked 's') the approximate locations of the main shear failures of the interconnections between the main piers and the secondary and buttress pier* (author).

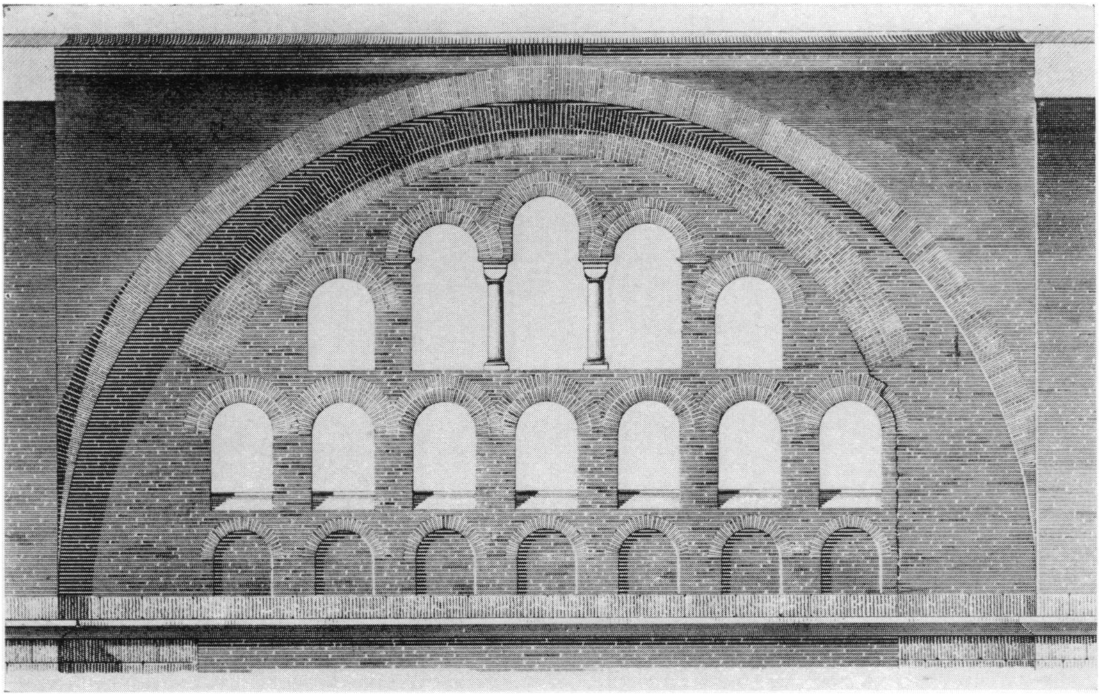

Fig. 27b *St Sophia: interior elevation (partly conjectural) of the south tympanum with the facings and later narrowings of the window openings removed* (Salzenberg, 1854)