Arches and Vaults in the Ancient Near East

Working with sun-dried mud brick and mud mortar, masons in ancient Egypt, Mesopotamia and the Levant built arches and vaults that were graceful as well as durable. Their methods are worth studying today

by Gus W. Van Beek

It is almost a truism among students of architectural history that the use of the arch and the vault began with the Romans. And indeed the Romans exploited those structures to the fullest, building them not only often but also on a monumental scale, in bridges and aqueducts, triumphal gates and amphitheaters that are still scattered through southern Europe. Yet the Romans did not invent the arch; nor were they the first to combine arches into vaults. By the time the Colosseum was erected, arches and vaults had been built in the Near East for about 3,000 years.

The few archaeologists who have studied the question are unanimous in the view that arches and vaults originated in the marshlands of Lower Egypt or Mesopotamia. The prototype was a structure built of bundles of reeds, which were placed upright in the ground, bent inward and tied together at the top to form a roof. Early Egyptian drawings, including hieroglyphs, depict reed vaults over sanctuaries, boat huts and other structures. Although no ancient reed buildings have survived, the technique has—in southern Iraq, at the confluence of the Tigris and the Euphrates, where a people called the Marsh Arabs still construct enormous vaulted buildings of reeds.

The outer surfaces of some of these buildings are covered with mud plaster. This type of construction, known as wattle and daub, is probably a relic of an intermediate stage in the evolution of the vault. Eventually most Near Eastern builders dispensed entirely with reeds (which in any case would have been available only in marshy areas) and came to rely on a more durable and massive construction material: sun-dried mud brick. Nearly all the surviving Near Eastern arches are made of mud brick, or adobe (a Spanish loanword from the Arabic *aṭ-ṭūb*). Even after fired brick was introduced most buildings in the Near East continued to be built of the sun-dried kind.

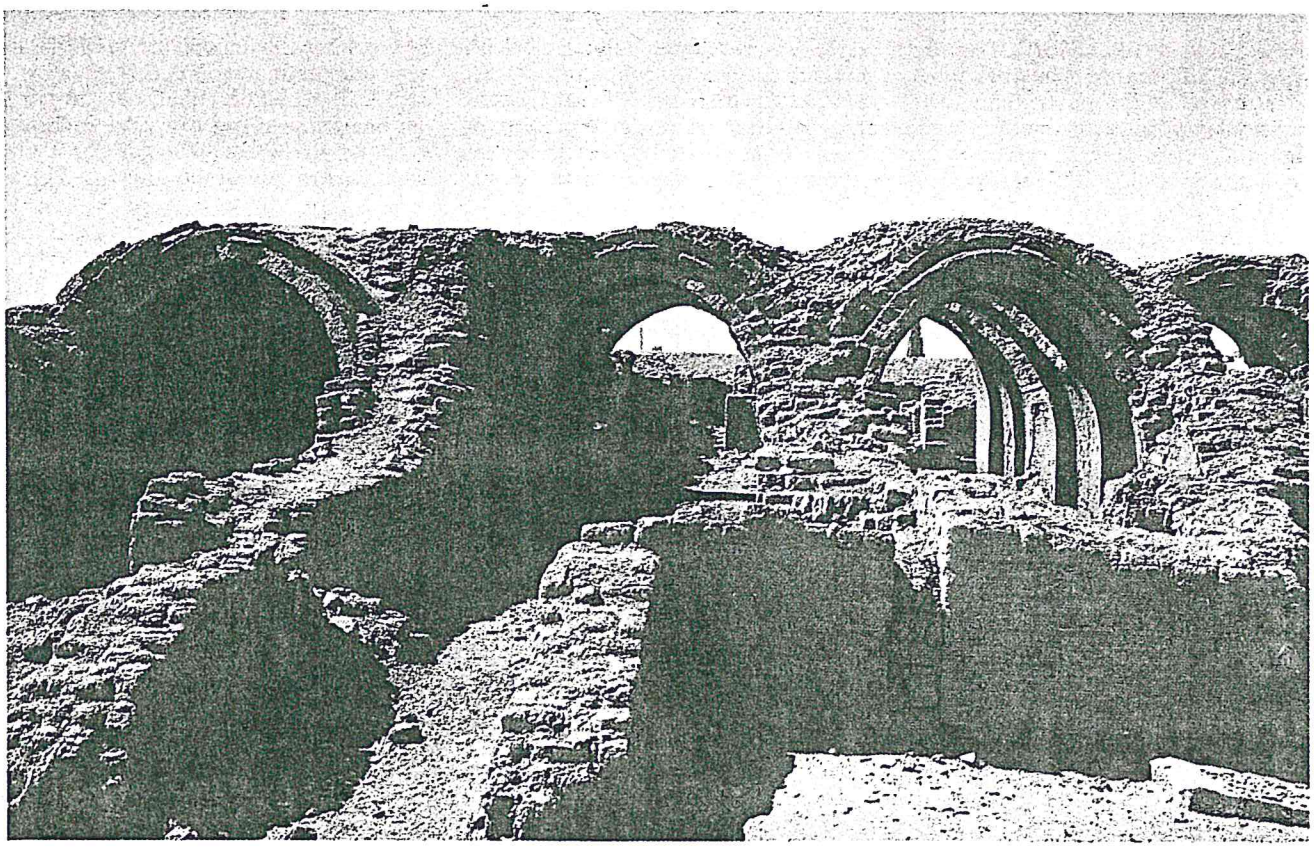
The reasons are easy to understand. Because mud brick is made of widely available ingredients—soil, water and chopped straw, with occasional additions of dung or sand—and because it is baked in the sun rather than in a kiln, it is one of the cheapest of all building materials; it is labor-intensive rather than energy-intensive. Furthermore, it is a poor conductor of heat, and so it is particularly suitable for arid regions where the daily variation in temperature is high. When the temperature climbs above 90 degrees Fahrenheit on a summer day, the temperature inside a mud-brick house stays in the 70's; in contrast, in a non-air-conditioned house built of prefabricated concrete, it can rise above 100 degrees.

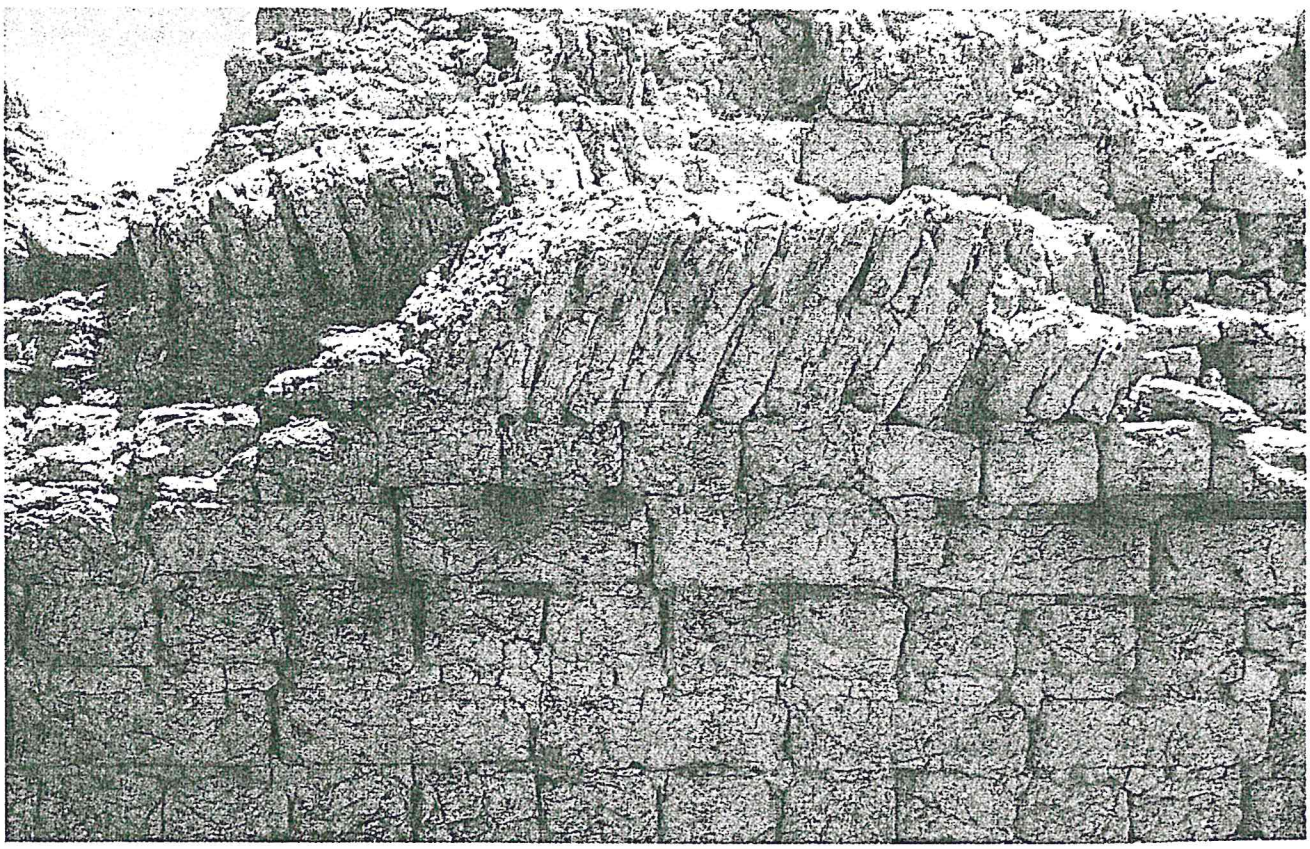
The same arid climate that makes mud brick the ideal building material in the Near East makes vaulting the perfect technique for constructing a ceiling or a roof. A vaulted ceiling allows hot air to rise higher than a low flat ceiling does and thus helps to keep the living space even cooler. More important, in many parts of the Near East there are no forests, and consequently the timber needed to support flat ceilings is scarce. A mud-brick vault requires no wood beams for support. Not only is it practical and economical but also it is a singularly graceful way to cover a building.

Three types of mud-brick arching and vaulting have been unearthed at Near Eastern archaeological sites. The first type, which probably looks most familiar to the modern eye, is the radial arch [*see illustration on page 98*]. In a radial arch the first layer of bricks was canted inward by setting small stones or potsherds in mud mortar along the outer edges of the side walls. The bricks were laid face down, and the long edge was aligned with the wall. (Typically the bricks were between 30 and 40 centimeters long and between nine and 12 centimeters thick; they have been found in both rectangular and square form.) The procedure was then repeated, and the layers of brick were canted at progressively steeper angles until the arch was closed at the top with bricks in a vertical or near-vertical position. In arched doorways and short vaulted passages the bricks in successive layers were usually laid directly on top of one another, but in longer vaulted rooms the layers were bonded, or staggered, as they are in the construction of a vertical wall.

It seems likely that the radial arch and vault evolved from corbeling, a technique that from the earliest times was common throughout the Near East and the Mediterranean region. In corbeling the successive layers of brick are cantilevered rather than canted inward; that is, each layer is laid horizontally but in such a way that it projects over the edge of the layer below. At Tell Razuk in Iraq a building dating from about 2900 B.C. displays what may be transitional evolutionary forms: vaulted roofs in which the successive layers are both corbeled and canted inward.

In Egypt radial arches and vaults were built sporadically in most periods of Pharaonic history, primarily in tombs and in monumental gateways. The earliest example known has been found at Helwan, in a tomb dating from late in the First Dynasty (about 3000 B.C.). A somewhat later but particularly instructive example is the arched gateway of a mastaba (a bench-

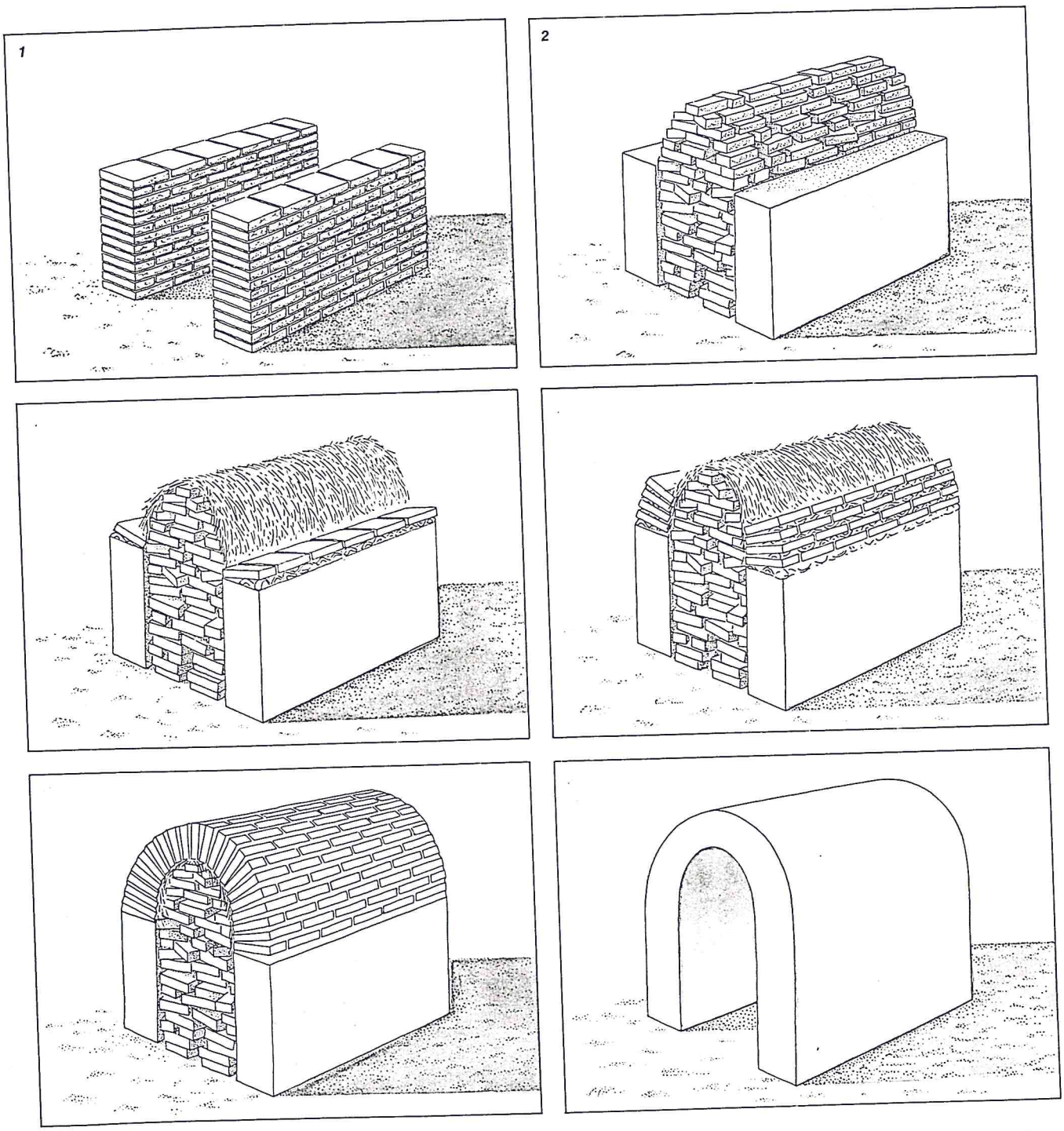




MUD-BRICK VAULTS support the storehouses (*top*) in the mortuary complex of Ramses II, the great Pharaoh who led the Egyptian empire to its final peak in the 13th century B.C. The complex, called the Ramesseum, is across the Nile from Luxor. Each storehouse is surmounted by a pitched-brick vault: the bricks stand upright on the side walls and lean toward one end wall. (The end walls have not survived.) Each vault consists of four courses, or layers, of brick; the photograph of the top of a side wall (*bottom*) shows how successive courses of vault brick lean in opposite directions. The storehouses held provisions for the Pharaoh's afterlife.

like tomb with inclined sides) at Giza that dates from the Fourth Dynasty (between 2680 and 2560 B.C.) and that belonged to the nobleman Neferi. The bricks on the inside of the arch were shaped to resemble arching reed bundles, with two half-round moldings on their interior surface; furthermore, the inside of the arch was painted a bright, rich red, the traditional color of dried reeds in Egyptian art. This unmistakable imitation of reeds is strong evidence that early mud-brick arches were modeled on a reed prototype.

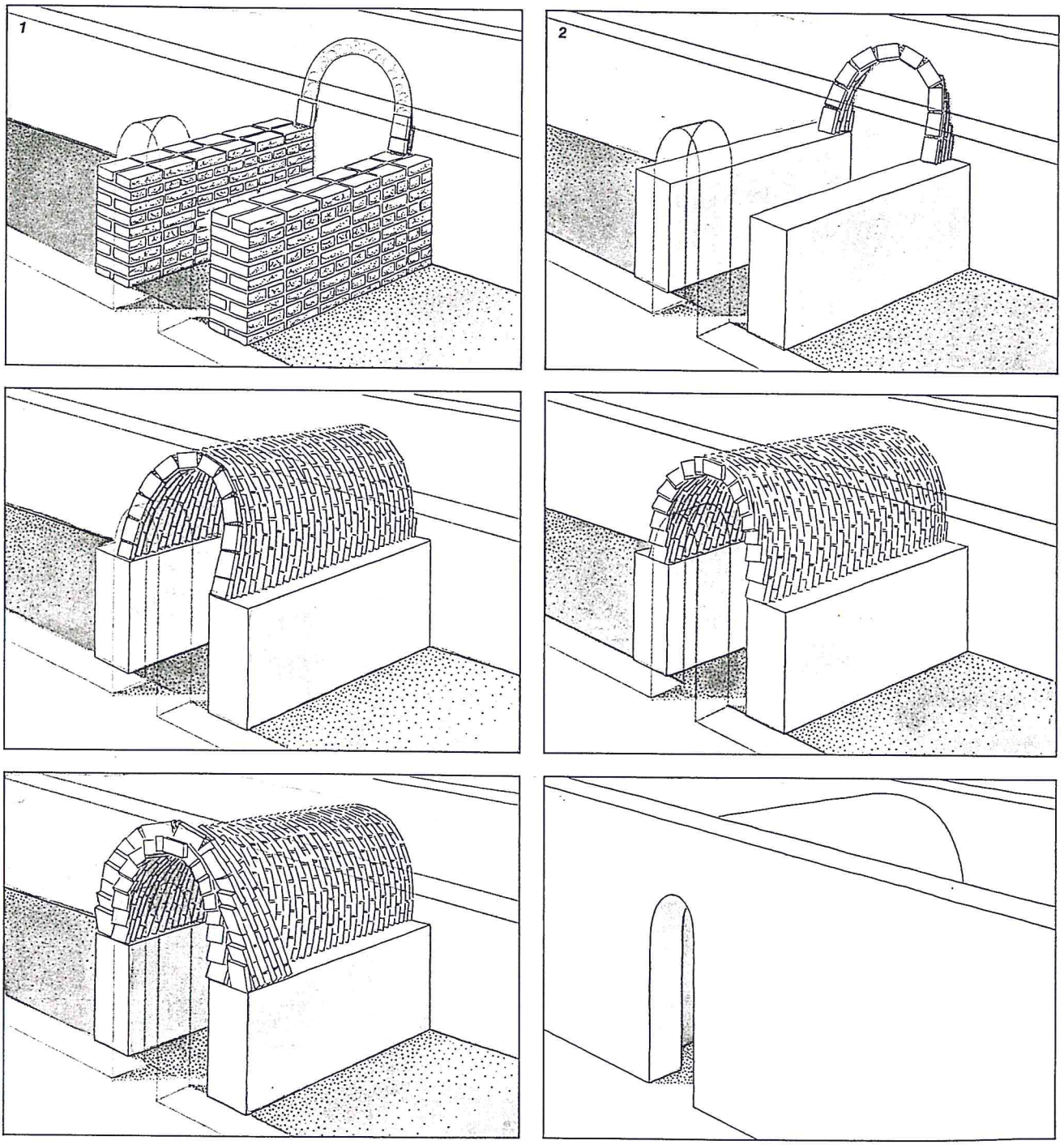
The possibilities of the radial arch and vault were more fully exploited in Mesopotamia, where they probably evolved independently and at roughly the same time as in Egypt. The earliest example known is in a hall built at Tepe Gawra late in the fourth millen-



RADIAL VAULTS were common in the Near East from the fourth millennium B.C. well into the first millennium A.D. The first step in building a radial vault was to raise the side walls to their full height (*1*). Mud bricks were then piled without mortar between the walls to serve as centering, or temporary support, for the vault (*2*). Mud mortar was spread on top of the walls, and small stones or potsherds were placed on the outer edges to cant the first vault bricks inward (*3*). The bricks were laid face down; the ones shown here are typical Mesopotamian square bricks measuring 35 centimeters across. Successive layers of brick were staggered and were also canted inward with stones and sherds (*4*) until the vault was closed at the top (*5*). Within a few days, when the mortar had dried, the support was removed; the vault was covered with mud plaster to help protect it from wind and rain (*6*).

nium B.C., at the time of the emergence of the Sumerian civilization. At Ur, the most famous Sumerian site, the tombs of King Abargi and Queen Shubad (built in about 2500 B.C.) had radially vaulted roofs and radially arched doorways.

The most impressive Mesopotamian radial arches and vaults are at Tell al Rimah, which dates from the end of the third and the first half of the second millennium B.C. In a temple complex at that site, vaulted ceilings span rooms that are as much as 3.8 meters wide; a stairway is supported by eight radial arches of progressively increasing height, and three vaulted passageways cut through a monumental entrance ramp to connect one terrace with another. There are also arched doorways, a vaulted burial chamber



PITCHED-BRICK VAULTS did not require temporary support during construction. The vault was outlined on an end wall with a thick layer of mortar, and the first brick, standing upright on the side wall and canted inward by stones and sherds, was leaned against the mortar (*1*). (Egyptian rectangular bricks are shown here.) Mortar was spread on the face of the first brick and a second brick was leaned against it; a third brick was placed on top of the second brick, canted inward and leaned against the end wall, and so on until the first arc was closed at the top (*2*). Successive arcs were laid against the first one until the opposite end wall was reached (*3*). The triangular space there was filled with smaller arcs and finally with stones, sherds and mortar (*4*). Often a second course, pitched in the opposite direction, was laid on top of the first one (*5*). The finished vault was covered with plaster (*6*).

and a series of radial arches on two levels that supported an overlying terrace or perhaps even a building.

Recent excavations in Israel have brought to light the first examples of mud-brick radial arches in the Levant. The oldest is an 18th-century-B.C. gateway at Tell Dan that consists of three concentric courses, or layers in thickness, of arch brick. At Tell Jemmeh, a site I excavated, four radial arches supported the floor separating the firebox from the baking chamber in a large pottery kiln built by the Philistines in the 12th century B.C. Elsewhere at the same site, in a cross wall that carried the roof of a large circular granary from the third century B.C., I found a mud-brick radial arch with the unusually large span of 4.25 meters.

Taken together, the various archaeological excavations have shown that radial arches and vaults were widely and diversely employed in the ancient Near East, from southern Egypt to western Persia and from late in the fourth millennium B.C. well into the first millennium A.D. The radial design, however, had a serious drawback: the arch or vault required centering, or temporary support, while it dried. Given the scarcity of timber, the commonest type of centering was probably just a dry, unmortared pile of mud bricks, perhaps covered with a bed of straw. Filling a doorway or an entire room with bricks and then removing them once the arch or vault had dried would have taken a lot of time and effort.

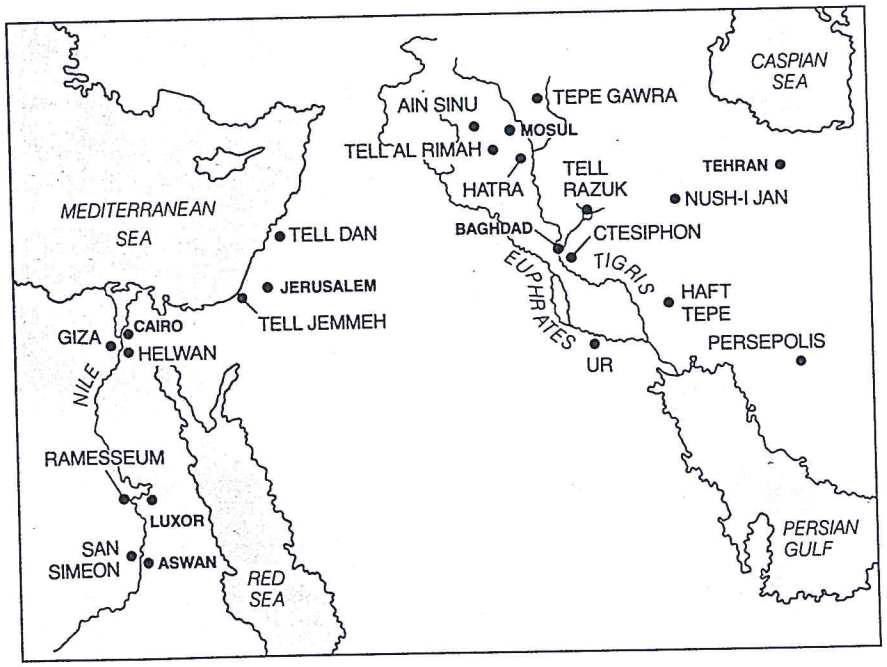
The second method of vault construction, the so-called pitched-brick method, avoided the need for centering. The bricks in pitched-brick vaults were lighter than those in radial vaults because they were generally smaller and thinner and also because extra straw was mixed with the mud. More significant than the weight of the bricks, though, was the ingenious way they were laid: they were stood on end and pitched, or leaned, against one of the end walls of the vault [*see illustration on preceding page*]. At the same time they were canted inward, like the bricks in a radial vault, by stones or potsherds placed under their outside edges. The finished vault consisted of a series of inclined arcs of brick; the hole left at the opposite end wall was filled with smaller arcs, brick fragments, sherds, stones and mortar.

Because each arc supported the next one, the construction of a pitched-brick vault could be stopped at any time and the vault would remain upright without interior support. Mud mortar spread thick between the arcs kept them from slipping. The suction of the wet mortar was augmented by an interesting feature of the bricks themselves: on one face (and in Egypt sometimes on both faces) each brick had a series of deep grooves gouged by the mason's fingers while it was still wet. The grooves allowed the mortar to act on a greater surface area, and the increased suction made for a stronger bond between bricks.

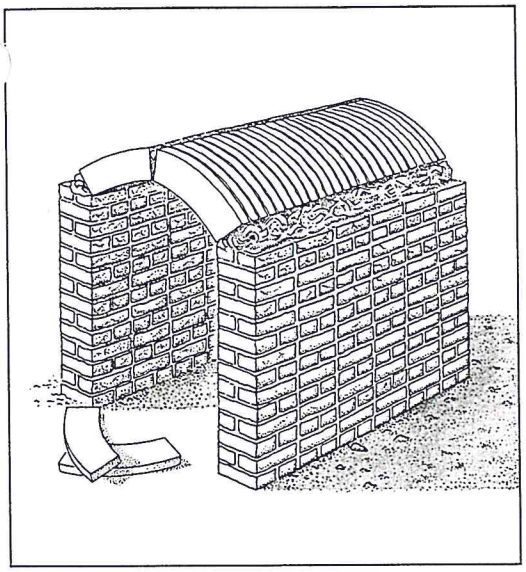
A number of variations on the basic pitched-brick technique have been observed. Occasionally a vault was built from both end walls; this was not particularly clever, because instead of having to fill a small triangular space at one end, the masons had to fill a larger ellipsoidal space at the center, where the oppositely inclined arcs met. Often, after a room had been covered with one vaulted layer of brick, the thickness of the vault was increased by laying additional courses over the first one. In Mesopotamia, where square bricks were the norm, one additional course was enough to achieve the desired thickness. In Egypt, where narrow, rectangular bricks were favored, vaults were often four or more courses thick. Alternating courses were inclined in opposite directions: the first course leaned against one end wall, the second course leaned against the other end wall and so on.

The earliest example known of a pitched-brick vault is at Helwan, in the same late First Dynasty (about 3000 B.C.) tomb that contains the oldest Egyptian radial vault. The mature design of the pitched-brick vault suggests, however, that the technique had been employed for some time and that older specimens either have not been preserved or have not yet been discovered. In the many vaults dating from the Fourth Dynasty some experimentation, mostly with the shape of the bricks, is still evident. One of the most interesting experiments is in the mastaba of the priest Sabef in the Giza necropolis. The bricks in that vault have triangular projections at both ends that made it possible to interlock them with neighboring bricks in the same arc. Theoretically such a design would yield a stronger vault. Yet shrinkage of the bricks as they dried might often have resulted in a poor fit, and the triangular projections would also have tended to break during construction. Presumably such problems explain why no other mud-brick vaults with interlocking bricks have been found.

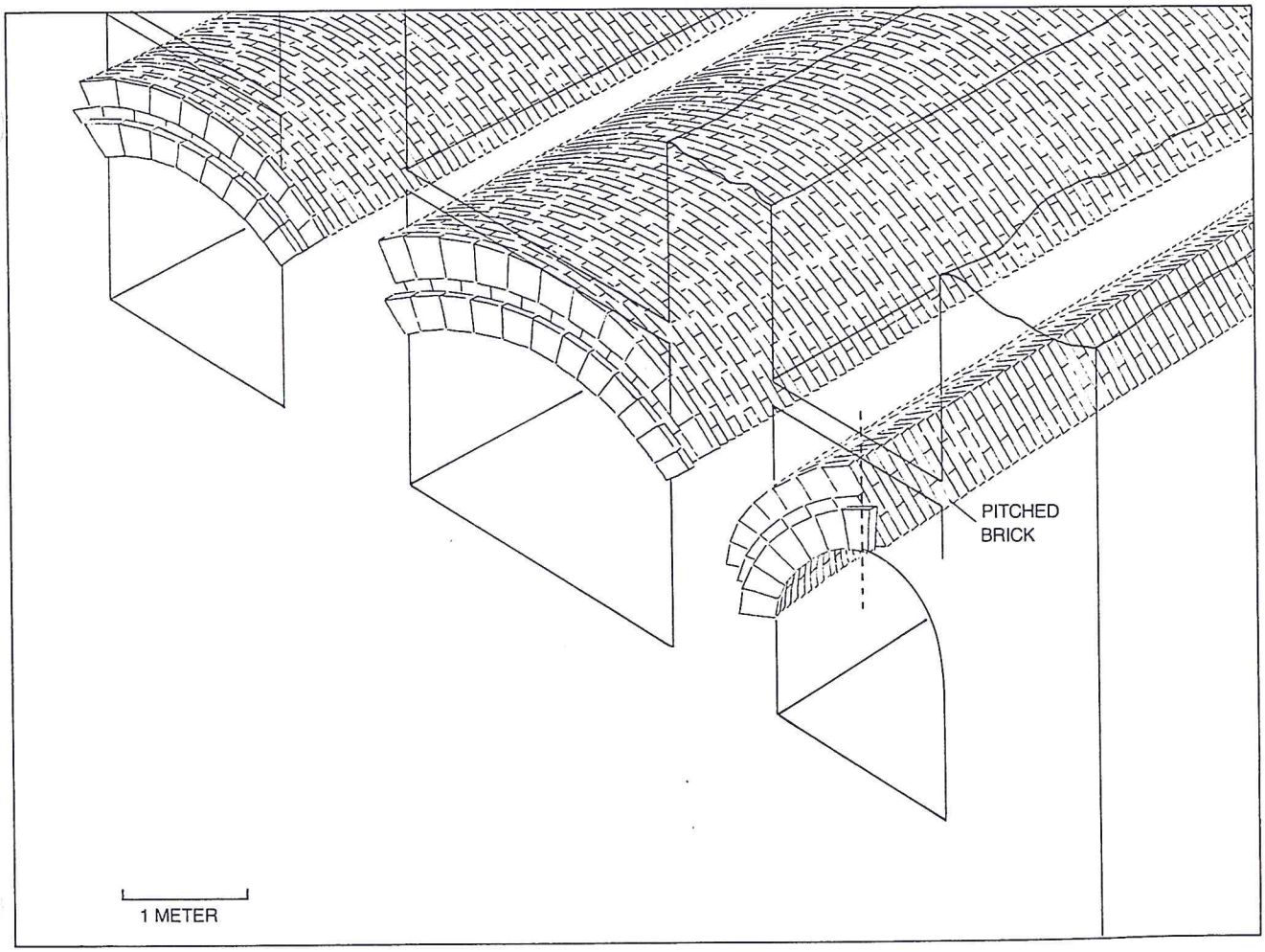
In contrast, barrel vaults built of rectangular pitched brick appear in every period of Egyptian history from ancient to modern, and in a wide range of applications: in burial chambers and associated offering rooms; as supports for ceilings and roofs in ordinary houses; in cupola-shaped ventilators on flat roofs; as supports for stairways and as covers for them, and in storehouses, churches and monasteries. Eventually pitched-brick vaults largely supplanted radial vaults. The radial design remained the best option for doorways or open-ended vaults, which lack the end wall required by the pitched-brick design, but in other



ARCHAEOLOGICAL SITES where brick arches and vaults have been found are shown on this map of the Near East. They are in Egypt, Mesopotamia (the valley of the Tigris and Euphrates), the Levant (the region bordering the eastern Mediterranean) and Iran.



RIBBED VAULTS were built with pairs of long, slightly curved mud bricks that leaned against one another over the center of the room. The spaces between the bricks and under their ends on the side walls were filled with mortar and potsherds. At Nush-i Jan in Iran a ribbed vault supported the floor of an upper room in a temple constructed between 750 and 600 B.C. (*right*). The bricks in the vault are 120 centimeters long. The site was excavated by David B. Stronach, now at the University of California at Berkeley.

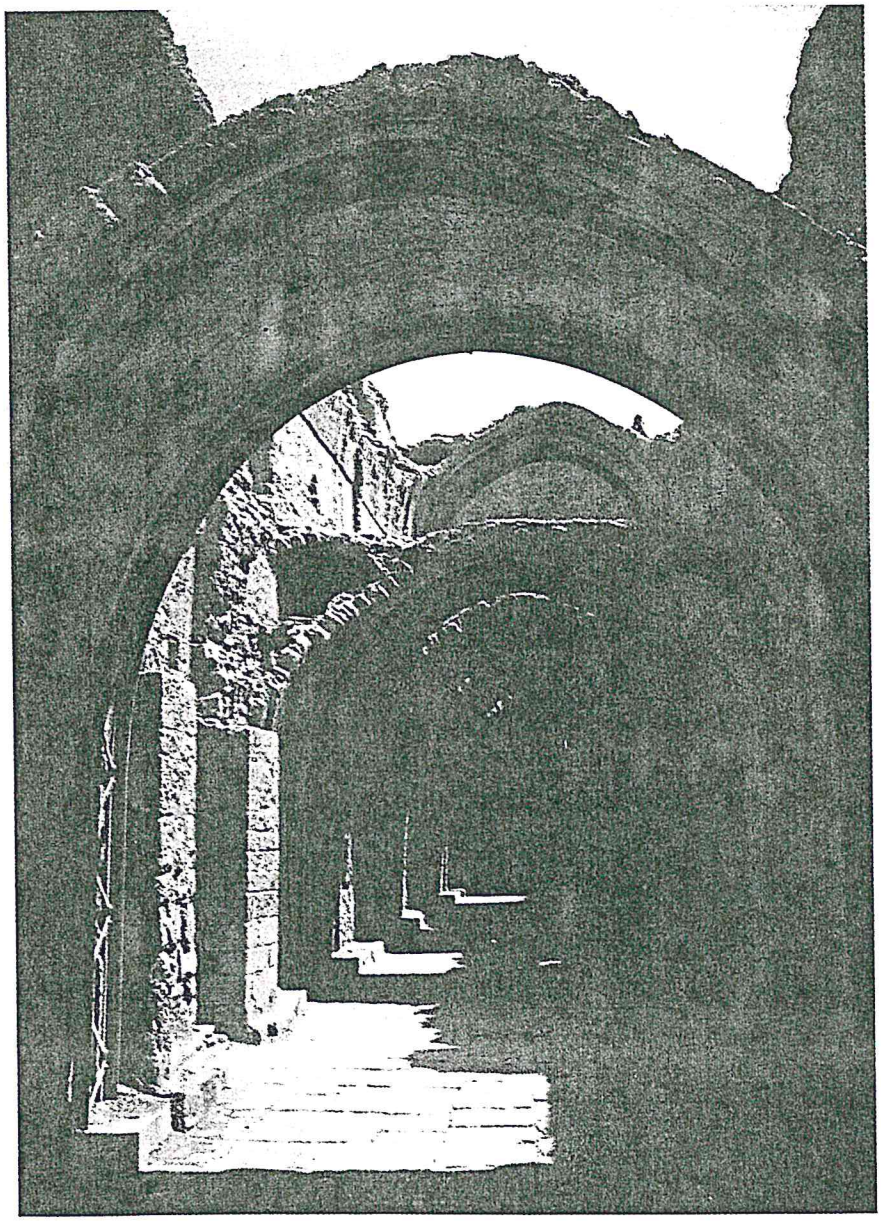


WEDGE-SHAPED BRICKS, or voussoirs, resulted in stronger arches and vaults. The oldest voussoir vaults are in an Assyrian building of the seventh century B.C. at Tell Jemmeh in Israel. The three rooms in the basement differ in width, but the ceiling vaults were built to the same height by tailoring the bricks' shape and by making the vaults over the wider rooms flatter. The vaults were one and three-quarters of a brick thick: in each of the two courses arcs of full-size bricks alternated with arcs of three-quarter bricks.

applications it survived primarily for reasons of tradition.

The finest vaults from the time of the Pharaohs are at Luxor, in the storehouses constructed by Ramses II (who reigned from about 1290 to about 1224 B.C.) in his mortuary complex, the Ramesseum. The long, narrow storehouses held provisions for the sovereign's afterlife. In each building the side walls are topped by four courses of corbeled brick; the corbeling creates broad platforms from which the thick vaults spring. Each vault consists of at least four courses of pitched brick, with alternate courses inclined toward opposite end walls.

The extraordinary adaptability of pitched-brick vaulting in both form and function can be seen in the Coptic monastery of San Simeon at Aswan, which was built in the seventh century A.D., nearly 2,000 years after the Ramesseum. The vaults that stretched the length of the church (and are now preserved only on the sides of the chancel) were not simple barrels: originally they were intersected by cross vaults in the nave. In the building housing the monks' quarters the pitched-brick vaulting over the ground-floor corridor was also an ingenious ventilation system. Secondary vaults occupying the space formed by the curves of the primary vault and the side walls served both to lighten the load on the primary vault and to channel cool night air into each monk's cell.

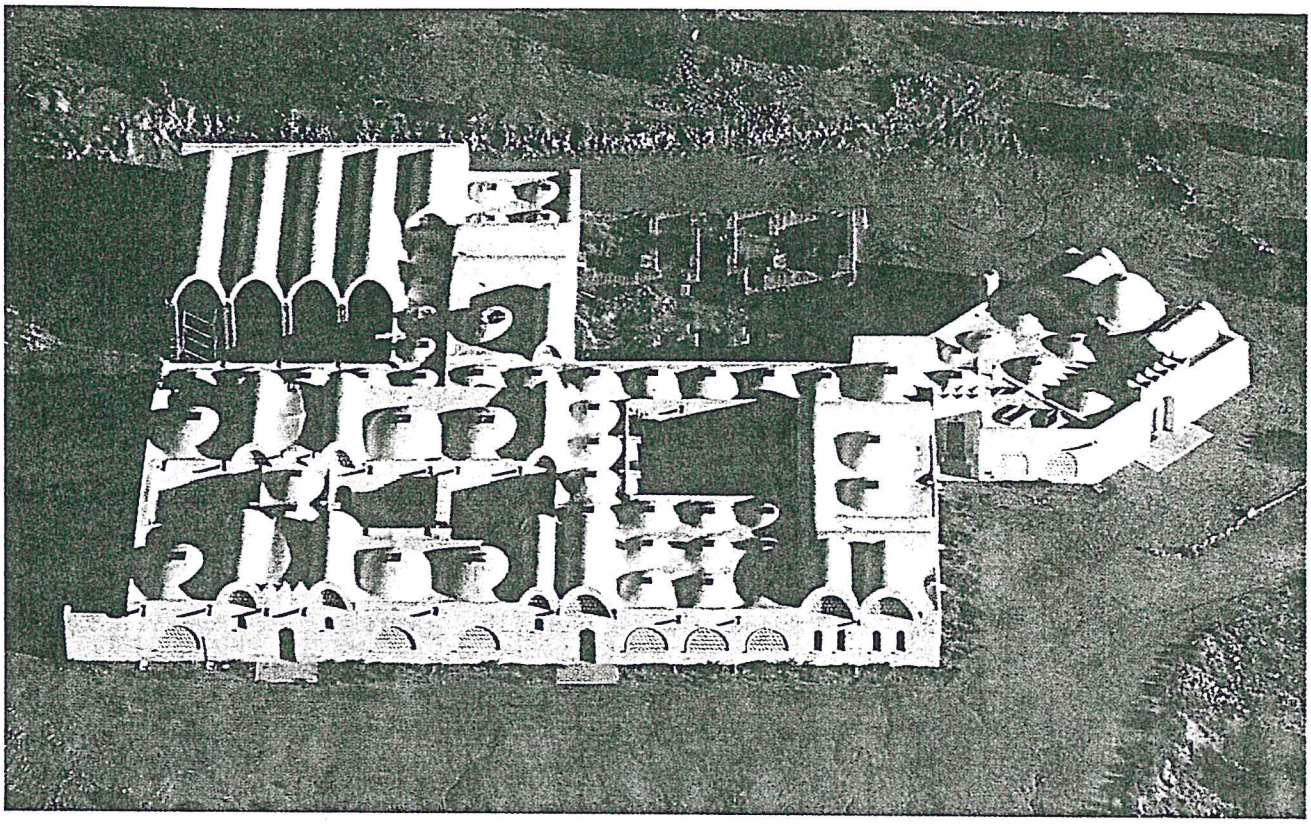


MONASTERY OF SAN SIMEON, built by the Copts at Aswan in Egypt in the seventh century A.D., contains striking examples of pitched-brick vaulting. The photograph shows a corridor in the monks' quarters. The vaults, which have since been reinforced with steel, supported the floor of another vaulted corridor on the second story. Secondary vaulting between the primary vaults and the corridor walls served to channel air into each cell.

In Mesopotamia the oldest pitched-brick vaults are at Tell al Rimah; they were built in about 2000 B.C., roughly 1,000 years after the appearance of the technique in Egypt. At Tell al Rimah there is in fact a series of vaults covering the entire period from 2000 to 1350 B.C. Some of them exhibit interesting variations in technique. For example, several vaults that helped to support a terrace or a building have a flattened, domical shape. In order to erect them the end walls were built to the same height as the side walls and a fan of brick (a pendentive) was laid across each corner in such a way that it projected up and into the room. The resulting octagonal opening was vaulted with arcs that leaned against the pendentives and the end walls.

Other Mesopotamian pitched-brick vaults have been uncovered in a temple from the 18th century B.C. at Tell Taya, not far from Tell al Rimah, and in the roofs of two 15th-century-B.C. tomb chambers at Haft Tepe in Iran. None has been found from the first millennium B.C., but that is probably just an accident of preservation and archaeological discovery. Pitched-brick vaults reappear in the first millennium A.D. at various sites. Indeed, the acme of pitched-brick vaulting is the Taq Kisra, the great hall of the palace at Ctesiphon, south of Baghdad, which was built sometime between the third and sixth centuries A.D. (There is no general agreement on the date.) The Taq Kisra was made of fired brick rather than of sun-dried brick. It still stands 28.4 meters high and spans 25.5 meters, making it the largest single-span vault of unreinforced brick in the world [*see cover of this issue*].

Judging from the archaeological record, the greatest technological advance in pitched-brick vaulting came not in Egypt or in Mesopotamia but in the Levant. It consisted in the introduction of voussoirs, or wedge-shaped bricks, which eliminated the need for inserting potsherds and stones under the outer edges of the bricks. Vaults built of voussoirs are inevitably stronger, because the bricks are in full contact with one another and the mortar is compressed in very narrow joints. Wedge-shaped bricks make it possible to flatten the vault and give it something other than a semicircular arc. This flexibility in turn enables an architect to design a building with vaulted rooms of different widths and still keep the ceiling or an upper floor at a uniform height.



MODERN MUD-BRICK VAULTS built in the traditional way support the buildings occupied by the Dar Al Islam educational foundation at Abiquiu in New Mexico. The complex was designed by the Egyptian architect Hassan Fathy. The structure projecting to the right is a mosque. The remainder of the complex is a school; the unfinished structure at the upper left will house the cafeteria.

Such was the strategy adopted by an Assyrian architect in about 675 B.C. when he designed the basement of a large building at Tell Jemmeh, where I found the oldest vaults known built of wedge-shaped bricks. The building is three rooms wide. Each room in the basement has a different width and a pitched-brick vault with a different arc: flattened in the two wide rooms and more semicircular in the narrow room. The average width of an individual brick in the vaults is 30 centimeters at the top and 24.5 centimeters at the bottom, but of course the bricks in the flatter vaults taper less than the bricks in the more semicircular one.

Ironically, in the same building the doorways between rooms were covered by a third type of vaulting, rib vaulting, that seems considerably less sophisticated than either the pitched-brick or the radial design. Six pairs of long bricks arched over each door; one end of each brick rested on a side wall, and the other end was propped against the opposite brick over the center of the doorway. The spaces between the brick ends and between the bricks and the side walls were filled with stones, sherds and mortar.

Rib vaulting appears to have been confined primarily to Iran; the technique may have been brought to Tell Jemmeh by a Median builder in the service of the Assyrian imperial forces. It was employed extensively at Nush-i Jan, a site in Iran that dates from between 750 and 600 B.C. The vault bricks there are huge: about 1.2 meters long. One would expect such long bricks to be fragile, but actually they were strong enough to support the floor of an upper room in the central temple. Nevertheless, a rib vault could not have been as strong as a pitched-brick or radial vault, and except for a certain simplicity of construction it probably had few advantages.

Voussoir brick, on the other hand, had distinct advantages, and yet it too did not receive wide application in the ancient Near East. Other than at Tell Jemmeh, voussoir vaulting has been discovered only at the Roman frontier post of Ain Sinu in northern Iraq. More examples may be discovered someday; if they are not, one can only conclude that the advantages of the technique were not considered worth the extra effort required to "custom make" bricks for each vault. Just as puzzling as the apparent failure of voussoir to catch on is the question of why it did not appear until the seventh century B.C.—why the Near Eastern peoples who invented writing, law, mathematics, astronomy and, more to the point, cities should have failed for more than 2,000 years to think of building their arches and vaults with wedge-shaped brick.

The invention of mud-brick arches and vaults, however, was in itself quite an achievement. Arch building never died out entirely in the Near East, and today it is enjoying a limited renaissance. The chief figure in that movement has been the Egyptian architect Hassan Fathy, whose brilliant and imaginative designs incorporating pitched-brick vaults have attracted a following not only in his own country but also in the U.S. As the advantages of mud brick are rediscovered by an energy-conscious world, the practical value of arches and vaults is becoming equally apparent.

Yet I do not want to stress only their practicality. Mud-brick arches and vaults are also beautiful. In a visual world too often dominated by rectangles and squares, they enable an architect to relieve the harshness and monotony of the straight line by employing nature's commonest form, the curve, in an almost infinite number of variations.

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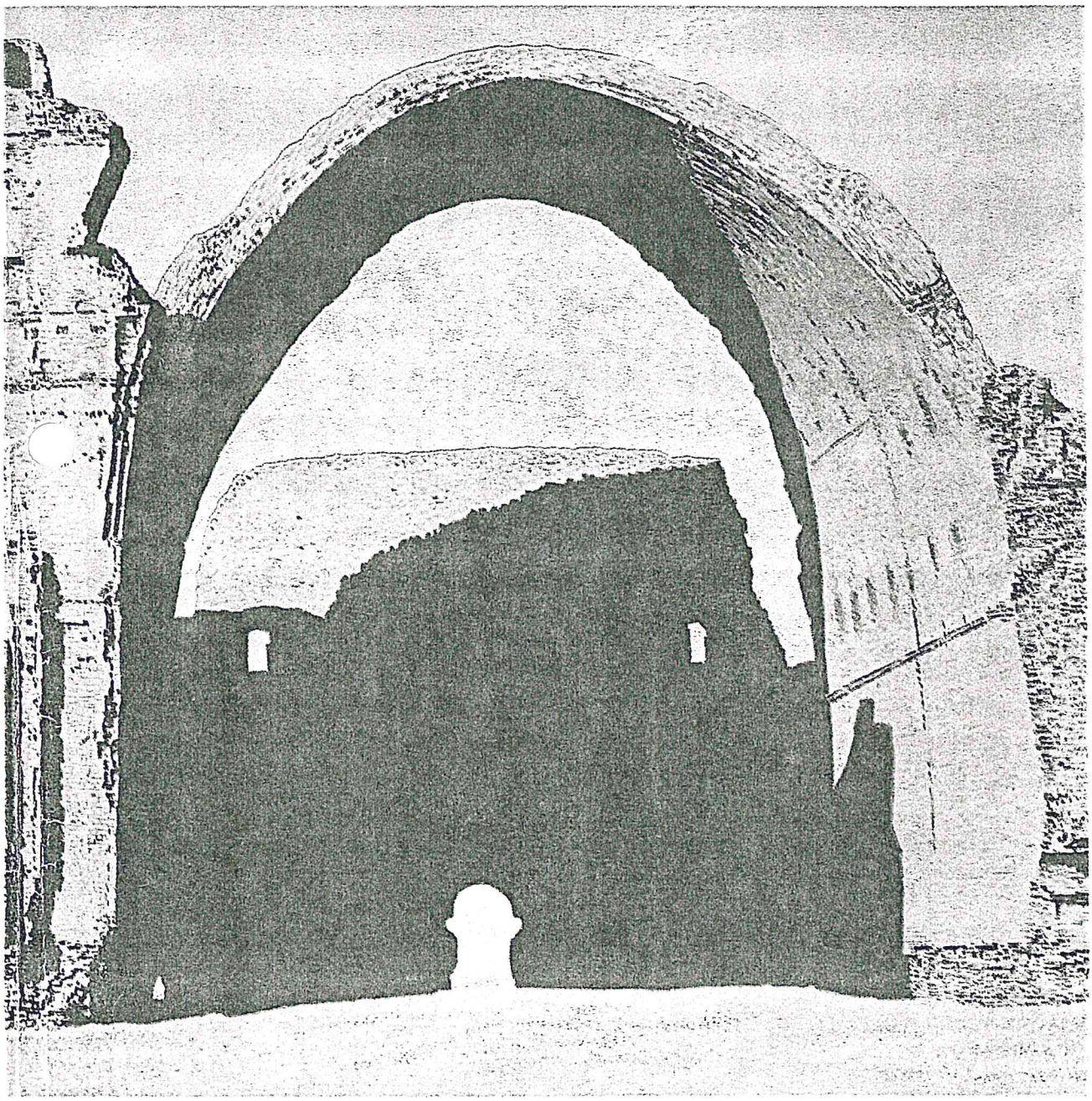

ANCIENT NEAR EASTERN VAULTS

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