	Load A (Outer walls)	Load C (Med. walls)		Stability A (Outer walls)	Stability C (Med. walls)	Vault Slope	Notes
Thinning Walls.	+	+		+	0		
Widening Spans.	+	+		+	0		
a Sloping Upper Zone	+	0		−	0		
b Negative Bot. " "	−	0		+	0		
b Inset " "	+	0		−	0		
c+e Outset " "	−	0		+	0		
f Unnecessary Steep Soffits	−	−		/	/		
g Vault Openings	/	+		/	+?		
h. Wide Capstone Exposure	+	+		+	0		For same v.h.: steeper soffit, ? For same soffit - reverse?
i Thick Roof-Caps	−	−		+?	+?		
j. High Vault Spring	−	−		−	−		
k. Piers in Facade	−	0		−	0		
l. Wide Facade Doorways	−	0		−	0		Limiting factor probably the lintels.
m. Columns	−	−		−	−		
n. Pilasters + Buttresses (inside)	+	+	(SL)	+	+		
o. Transverse Partitions	+	+	(SL)	+	+		
p. Vault Beams	0	0		+	+		
q. Roof Combs	−	−		−	−		
r. Flying Facades	−	/		+	/		
s. Second Stories	−	−		±	±		
t. Use of Old walls	−	−		−	−		
u. Space Limitations	±	−		−	−		
v. Function.	−	−		−	−		
Wooden Cap beams							

For given span

+ with q

Stability of Maya Vaulted Buildings.

The mechanical problems which confronted the Maya architects in designing a ~~stable~~ masonry-roffed building which did not fall down of its own weight are rather complex to a ~~mixman~~ layman. Since most archeologists,(like the writer), are laymen in the this respect, an account of those problems should be useful, and should be as simple as possibily. The initial statement of a number of definitions and principles, properly distinguished so that we can refer to them without restatement, will be helpful.

a. "Structures are artifical constructions in which all parts are intended to be in equilibrium and at rest relatively to each other . . . they consist of two or more solid bodies, generally called pieces or members, which are connected at different parts of their surfaces called joints".

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Kidder-Nolan, 19 p.124

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b. There are two varieties of motion. "A moving body has a motion of Translation when every straight line in the body ~~moves~~ remains parallel to its original position. Thus . . a sled moving down ~~hill~~ a uniform incline has a motion of translation".

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Duff, p 6.

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c."A body has a motion of rotation when all points in the body travel in circles the centers of which lie in ~~straight line~~ a straight line; the line is called the axis of rotation. This is the motion of a grind stone . . or a swing."

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Duff, p.6

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d."A change of position is called a displacement", and ~~if the change is due to a motion of translation~~, it is ~~measured by~~ described by "the length and direction of the straight line drawn from the first position of the point to its second point".

Duff, p 8

e."Force Xixxthat is a name which we give to that influence of one body on another by which the first changes the motion of the other". Another definition: "Force is that which changes, or tends

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Duff p.28

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to change, the state of rest or motion of the body acted upon". In

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Kidder, p.124

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our discusion all forces considered will be those of one member of the building acting on another, and causing or tending to cause a change from a state of rest to one of motion, and the forces which must be brought to bear against them.

f. "Action and reaction are equal and opposite" (Newton's Third Law of Motion). "The action and reaction here referred to mean force and counterforce". This principal means that if a

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a wall presses down on a floor with a force of so many Lbs. per square inch, the floor presses up on the bottom of the wall with a force of an equal number of Lbs. per square inch.

g. The center of maxx gravity is, to all intents and purposes, here the same thing as center of mass, which is defined thus by Duff: "The center of mass of a body moves as if the whole mass were concentrated at the center of mass and the forces acting on the body were transferred, with there directions unchanged, to the center of mass." Notxthat If the center of mass moves, the body

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Duffpxxxxx- -
Duff p 64

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is of necessity move by translation, and in calculating what forces must be brought to bear to prevent this kind of motion, we are, under this definition, free to bring them all to bear on the center of mass or gravity. But ifxweznztnallyxdidxso we may not do so in considering rotational forxxx effects of the same forces, as we would be eliminating the lever arms on which they work. In this latter case we may not treat the body as a particle.

hxxMomentx

h. Rotational movement is not created merely by a force, axting but by a force acting on a lever arm. One might exert a large force on the xxlaxxafxx hub of a fx wheel without turning it, while a slight force applied at the rim, or on a spoke, would start it turning. "When we speak of the moment of a force, we must have in mind some fixed point or line with respect to which the moment is taken. The moment of a force is the product of the mgx magnitude of the force and the perpendicular distance from the point of to the line of action of the force; or in other words . . the product of the magnitude of the force by the arm with which it acts."

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Kidder-Nolan, p 289

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i. "Conditions of equilibrium.: The forces acting on a body are in equilibrium when they cause no acceleration either linear or angular, that is, when their resultant is zero. Given that a system of forces is in equilibrium we may conclude that the some of their components in any direction equals zero, since there is no acceleration of the center of the mass, and also that the sum of the their moments about any axis equals zero, since there is no angular acceleration about any axis." ~~This is to say that~~

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Duff p 78

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~~if a Maya half-vault is in equilibrium, every force tending to move it as a whole in one direction is, ~~reduced~~ met by an equal and opposite force from some other member; and that the lever arm~~

This is to say that the total effect of all forces tending to move a Maya half-vault, ~~in some~~ let us say to the left, is met by an equal total of forces working toward the right; and that lever arms of ~~all~~ both ~~forces~~ sets of forces are so adjusted, each to its own force, that the total of rotational power (moment) in one direction, is matched by a total in the other. In the definition, "angular acceleration" means change in rotational motion. The term also implies ~~such a change at~~ relation to time, which does not need to convern us here. For our purposes equilibrium means that all forces acting on any member are so balance ~~adjusted~~ that no motion (~~displacement~~) ~~either of~~ either of trabslation or of rotation, takes place. Any motion would, of course, result in the displacement of one or more members.

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The resultant of two or more forces is definee as the single force which will produce the resultant acceleration" ~~Axxxxxxx~~ The

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Duff p 36

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~~Accelerationxisxratexofxchangexinxvelocity~~
~~resultant~~ The ~~xxxxxxx~~ acceleration is a change in velocity in which we are not interested. The important thing is that the particle acted on by the two forces will move along the line of this acceleration. Velocity, of course, implies direction.

"In considering the action of forces, it is convenient to represent them grapgically by straight lines . . The length of the line, if drawn to a scale of pounds, represents the magnitude of the force in pounds; the position of the line indicates the line of action; the arrow head .. the direction in which it acts. .. If two forces ~~are~~ applied at one point are represented in magnitude and direction by two straight lines inclined to each other, their resultant is the diagonal of the parallelogram formed on those lines" It is here implied that not only is the direction of the resultant represented by the diagonal, but also the amount of the resultant force (to be read at the same scale used for the original forces.

"A force may be considered as acting anywhere on its line of action". ~~Thisxisximportantxasxitxwill~~

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Kidder-Nolan, p 298.

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It will readily be conceded that masonry vaulted buildings form one of the largest categories of Mayan archeological remains, at least of the classical and late periods. They must be as thoroughly explained as possible in any complete account of the Maya culture, and before this can be done, must be correctly arranged in chronological series.

It is now obvious that neither the unique accurately dated monuments of this culture nor the variations in architectural decoration of the buildings themselves and the minor details of their design will alone serve this purpose.

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Vaillant, 1932, p. 2 Merwin and Vaillant, p. 2-3.

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As excavation progresses it becomes increasingly apparent that pottery, indispensable for the earliest periods, will become one of the best time indicators for the classical and late periods. But probably a large majority of Maya

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For results at Uaxactun see Vaillant, Smith, : at Holmul, Vaillant, 1932.

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buildings, even when restricted to these roofed with the masonry vault, will be found without unequivocal ceramic associations as well as with their decorative details and minor points of design completely obliterated.

All time-indicators possible should therefore be developed to the fullest possible extent. This paper is a discussion of one of these which the writer believes can be used, in studying vaulted buildings, to a greater extent, and with more precision than has been common--the relation of wall thicknesses to room widths.

Tables reflecting these measurements at two Usumacinta sites are appended and discussed by way of trial balloons.

Chronological deductions based on this relation, or more generally, by direct comparisons of wall thicknesses, are by no means new. The purpose here is to discuss some of the limitations on the method, and to suggest that where these limitations are absent or can be discounted, more precise determinations than have been the rule may be attempted. The assumption involved is that, because of technical inability or lack of engineering knowledge, perhaps both, the Maya architects at first designed only narrow vaults, and placed them on very thick walls; and that as time passed, they learned to erect wider vaults, or to place them on thinner walls. This assumption is implicit in one of the reasons given by Spinden for considering the famous Palenque buildings as late: "Perhaps the strongest evidence of the lateness of Palenque is seen in the architecture. In Palenque are found the widest rooms, the thinnest walls, the most refined shapes, and the most ideal interior arrangements to be found anywhere in the southern and western part of the Maya area". Lothrop finds walls growing thinner

Spinden, 1913

with the passage of time at Tuloom, and the principal is noted by Pollock,

Lothrop, 1924, p. 170

Thompson, Pollock and Charlot, 1932, p. 117

and was used by Vaillant in his analysis of Holmul architecture, and to a certain

Vaillant, 1932

degree, of Maya architecture generally.

Reasonable conjectures as to the motivation for such a change are not far to seek. The thinner the wall the better light and air is admitted through doorways and, where they exist, ventilators. The thinner the wall the less labor in quarrying stone, in cutting it where cut stone is used, and in burning lime and transporting all materials. The wider the room, surely for some purposes, the more convenient and useful.

The structural factors which limited the Maya architect, at any given time and place when he determined the thickness of his walls and the span of his vaults have been most fully discussed by Roys, on whom the writer draws freely,

Roys, 1934.

without intending to avoid responsibility for statements made. They belong to two categories which affect wall thickness and span--stability and strength.

The reader should recall that, reduced to simplest terms, a Maya vaulted building consists of essentially of vertical walls, on which are placed masonry masses so shaped as to form the ceiling of the room. On the outside these may rise vertically or on a slope (giving a mansard roof effect) but always the inner surfaces slope inward and upward until they nearly meet over the center of the room. The small gap is usually closed by laying a line of slabs across from half-vault to half-vault, and a masonry roof-cap, surfaced with concrete, is placed over all. Whether the overhanging inner slopes are faced with corbeled slabs or tenoned veneer stones, each half-vault tends to act as a monolithic unit, as does each wall, due to the liberal use of mortar in both.

It is apparent that the vault as a whole, when completed, must be balanced in some fashion on the walls. In many cases each half-vault has its center of gravity over its supporting wall, and not over a point in the room. Such half-vaults act as cantilevers, and each is independently stable (See Fig. 1). But if the two halves overhang so much that they lean against each other at the top (exerting pressures in opposite directions through the rough cap,) then compensating outward side-thrusts will result at the base of each half-vault. (Fig. 2). Since the bottom of the half-vault is on the top of the walls and the two are locked together by the weight of the upper unit, there will be a tendency to push the walls over in the direction of the thrust--that is, outward.

In this connection, the thicker the wall, the wider its base, and the better will it be able to resist such side-thrusts. In practice the wall usually fails to act as a monolith and breaks. The thicker it is, the more masonry there is to be broken apart, and the less tensile strength per square inch dies its mortar require to prevent such a break. Other things remaining equal, therefore, an architect who thins his walls has reduced his margin of safety in the matter of stability. If he does so without collapse, he has made progress.

On the other hand, if he uses the same wall-thickness but increases the span, he has also reduced the same margin of safety, by increasing the thrust, unless he compensates in other ways. Using the same soffit slope for the inner surfaces of his vaults, they must rise higher, in order to nearly meet at the center, will weigh more, and over-hang more, and thus increase the amount of side-thrust, if this was present in the design for the narrower room, or tend to introduce it, if it was not. If he chooses to keep the height the same, he must make his vaults flatter, in order to have each half reach nearly to the center of the room. This will also increase the side-thrust, since ~~a larger amount of masonry will extend over~~ the center of gravity of the half-vault will move toward the center of the room, and its mass increase. the room. Thus, thinking only of problems of stability, either thinner walls, or wider spans, and of course, both combined, represent more advanced design from a structural point of view— they require more skill or knowledge to successfully achieve.

~~However, in a great many buildings, each half-vault is made to balance itself, as noted above, and no side thrusts are exerted on the walls. Whether this is so or not, a~~ A main function of the wall must of course always be to merely support the weight of the heavy vault--it must resist the pressure--the more downward load--which tends to crush it. Again, if other things remain equal, a thinner wall will either more nearly approach the danger point, which implies more accurate knowledge of the strength of the masonry, or it must be made stronger, which implies its improvement. The load per square inch has been increased, since the number of square inches has been reduced.

If the room is made wider for the same walls, the total load, and therefore, the load per square inch, will probably be increased. (Fig. 3). This is because the vault is wider in any case, and probably in most cases ~~much~~ higher, since variations in the soffit slope angle are unlikely to actually reduce the vault height in the wider room. If they do, the flatter soffit will require a thicker outer wall, at least, because of threatened instability. There must be more material--greater weight--in a wide vault of the simple type thus far considered, unless there is such a reduction. Such a reduction could only be effected by flattening the vaults--making the soffit more nearly horizontal. The possible relationship between soffit slope angles, and walls and spans, is discussed below under "flat vaults."

From the point of view of masonry strength then, either thinner walls or wider spans, or a combination of both, other things being equal, represent a more advanced design. This may involve merely greater daring or knowledge on the part of the builder, or actual improvement in the masonry--in the quality of the mortar, better selection or cutting of stone, better chinking, etc.

The above discussion has been indulged in to bring out the fact that even if we are not able to say, in a given case, whether problems of stability or of masonry were to the front, progress in either category may be reflected in the wall thickness or vault span, or both, and confusion as to which type of limitation was involved does not necessarily vitiate the conclusion, that progress in one of the other was made. However, the particular design of the vault itself (especially the outer part forming the) may greatly increase the side-thrust and thus inhibit progress in wall or span dimensions (Fig. 4). This is more fully discussed later.

For the above simple cases direct comparisons between the walls of different buildings, and between their spans, appear sufficient. But changes in wall thickness or room width were very probably sometimes made without any technical advance, by adjusting one dimension to the other. Thus, for cultural reasons, it might be imperative to erect a palace with a wider room than a contemporary temple. The margins of safety, both in stability and load on masonry, could be made the same in each by making the palade walls thicker than those of the temple. It seems to the writer that in order to guard against this situation, the actual measurements of walls and rooms should not only be compared directly, but by percentages expressing quantitatively the relation of wall thickness to vault span. If, for example, the wall thicknesses of the two above hypothetical buildings are divided by their respective room widths, each giving the same percentage, and the buildings are of the same general design when seen in cross-section, one is no more advanced than the other from this point of view. The wall-span ratio indicates contemporaniety, which, in an actual case, should be checked by all other available criteria. If, however, the palace index, de-

~~spite the thicker palace wall, is lower than that of~~

spite the thicker palace wall, is lower than that of the temple, the wall thickness only partially compensates for the greater span, and some advance may be suspected.

An ideal index is one which reflects icreased loads on walls and closer approaches to instability, and one which also can be applied to the greatest number of buildings. The ratio of all wall thicknesses to room widths (measured, of course, on a cross-section) does not meet the last requirement, though perhaps it should be figured and used as between buildings of the same cross-section type. The difficulty is that Maya buildings, even when probably contemporary, do not conform to a given type when seen in cross-section. Three examples will suffice. A simple one-room temple will have a front and rear wall, with half-vaults springing from each and nearly meeting overhead. To get the index for the whole cross-section the thickness of two walls will be divided by the span of one vault (or vice-versa). But another building may be erected against the side of a hill or the substructure of another building. It may have the same front wall, the same vault, but its rear wall will be a mere retaining wall holding back solid fill placed on the steeply rising ground behind. (Fig. 5). The thickness of the rear wall, for obvious reasons, is only half what it would be if it were free-standing, or else the whole hill must be considered the wall. There is here no second complete free-standing wall to measure.

Neither of these types can be compared with the many double-ranged buildings where a single medial wall serves two half-vaults--the inner half-vaults of front and rear rooms. (Fig 6). The ratio of two walls to one room (the simple temple) cannot be compared to the ratio of three walls to two rooms ((the double-range temple or palace).

Even when we are dealing with buildings similar in cross-section, if they involve this medial wall supporting two half-vaults, a percentage reflecting all walls and rooms has one drawback. It will not fully reflect changes in room widths and outer wall thicknesses, because the outer wall thicknesses tend to change faster than the medial wall thickness (which supports twice any increase in vault weight). This was noted as a general characteristic by Pollock.

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Pollock, 1932, p. 117.

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In order to compare wall-span ratios it seems to the writer permissible and logical to use an index reflecting only those of the elements under discussion which are common to all vaulted buildings. These are the outer wall thickness and the outer room width. These two elements will be found on all Maya buildings, whether there are one, two, three, or more ranges, and even where there is no free-standing rear wall. It is fortunate that where there are inner walls the outer is the one which varies most, so that such an index is not only most universally applicable, but is also the most delicate. Further, from the point of view of stability, it is only the outer walls which may be called upon to resist side-thrusts, and the failure to take account of interior room-widths is of no consequence so far as stability is concerned The only thing lost is an indication of the increased load on medial walls in double or multiple range buildings. Among buildings having this element in common perhaps this load could best be studied separately. A useful index might be the thickness of the interior wall divided by the sum of the widths of the two rooms it serves.

If a building yields more than one index of the sort proposed--outer wall thickness divided by adjacent room width--it is the lowest ("lightest") which should be used for comparative purposes. If the builder was able to erect a half-vault and its wall of a given degree of lightness, let us say the front, it is obvious that he could have built the rear outer half-vault and wall of approximately the same proportions.

Front and rear walls are by no means always of the same thickness. Sometimes the room which the thicker wall serves is wider and the reason is obvious, and the proposed index, when applied to the rear, will reflect the situation.

In other cases--perhaps a thicker rear wall of a single-room temple--the added thickness may be to allow for a niche, or a roof comb or flying facade placed to the rear. In any case, it seems most probable that where indices differ at front and rear, the heavier most probably results from factors extraneous to vault building ability pure and simple.

To simplify matters in the exposition above, we have taken up various factors individually, assuming all others to remain the same. Unfortunately, they do nothing of the sort. If the Mayas straight through had had but one desire--to erect as stable vaults as possible, with the largest spans on the thinnest walls they could manage, the wall-span index would be always true chronologically. And it would be the most useful imaginable, since the most complete collapse of a vaulted building usually leaves something of the walls. But many other factors surely were, or may have been, at work. Wherever particular buildings, or series of buildings, are to be compared chronologically on the basis of wall or span dimensions, or by indices based on them, such extraneous factors must be satisfactorily accounted for. The writer believes this can be done at many sites, if there is opportunity for extended excavation at each site, or if the buildings are standing and thoroughly described. As between two thoroughly known sites, valid comparisons will probably be possible, provided the techniques in use are not too disparate.

Following is a discussion of factors which may in given cases, have caused a deviation from the wall and span dimensions which the builder knew, at the time, he could have used successfully, if his problem had been to span the room with a masonry vault, and nothing more. Where design is under discussion, the standard of comparison is a half-vault with vertical outer surface ("upper zone") in the plane of the outer wall below, with an inner soffit slope of a moderate angle, placed on a wall of moderate thickness, and used with a room of moderate width. Fig. 1 illustrates such a hypothetical standard, and explains the names here used for various elements in a vault. The theoretical effect of the occasional absence of an off-set at the spring of the vault, and the minor variations in its width when present, are disregarded as inconsequential. We have also omitted any allowance for the weight and stabilizing effect of medial and upper mouldings or cornices, except such part of the former as is included in a downward projection of the plane of the upper zone (sometimes called the "entablature", or "upper facade".

Three factors may be present and affect the stability of the half-vaults, apart from the base supplied by the walls.

a. A sloping upper zone in the facade reduces the cantilever effect of the half-vault by reducing the stable portion over the wall which tends to balance the overhang, and this increases the tendency to side-thrust.(cf. Fig. 1 with Fig. 7). The less steep this slope, the greater the thrust effect. (Fig. 7) If stability happens to be a critical matter, this design would tend to raise the index; if not, to lower it, since weight is reduced.

In northern Yucatan the sloping upper zone is often structurally present, - though concealed by ornamental veneer. The later is roughly triangular in

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cross-section, with one point resting on the outer part of the wall or on the medial moulding, with the hypotenuse of the triangle following the sloping upper zone of the previously erected outer half-vault.

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Such an arrangement gives a vertical or even negatively battered upper zone, but the usualy monolithic character of the whole is absent, because the veneer is not bound to the half-vault. Such a construction adds, rather than otherwise, to thrust tendencies, of sloping upper zone vaults, but presents the same load as a vertical upper zone design. Its effect is therefore to raise indices, if anything, not to lower them.

This method of construction is known to occur in Northern Yucatan in purely

Maya buildings, where it was noted on   by Martin. Roys called attention to its presence in the House of the Magicians at Uxmol, where the writer has observed it also in the House of the Governor and the House of the Turtle. Perhaps it represents in advance in specialization of workers--vault builders as opposed to workers in stone mosaic facade decoration, which is the type of ornament applied to the buildings in question. Where, as here, the facade was to be erected separately, originally sloping upper zones were necessary so that the facade element could be thicker at the top and so lean inward, and not be in danger of falling outward.

b. Setting the base of the upper zone behind the plane of the outer wall surface (a frequent practice in the Usumacinta) has the same effect as a sloping upper zone. For convenience we may call this an "inset" upper zone. (Figs. 5 and 6).

If either of the above factors, alone or in combination, have the result of making the half-vault unstable and introducting side thrusts on a wall which could otherwise have supported a stable half-vault, there is the possibility that the wall had to be left thicker ~~or the room made narrower~~ to withstand the thrusts, or the room made narrower to reduce them, with a resultant higher index. Progress is here best measured by actually calculating the margins of safety from the point of view of stability. If all these margins are wide in all buildings under comparison, these design factors have probably not affected the wall and span dimensions, unless to reduce them by lightening the vault weight. The latter effect should be considered true progress--in design rather than masonry technique--and the lowered index would retain its meaning.

The important caution here is in dealing with completely collapsed buildings where the vault-design is unknown. In such a series, a building with a low wall-span index may be earlier than another with a higher index, the latter made necessary by a vault design made more unstable for aesthetic reasons.

Unstable vaults are of course lighter than stable ones of the same span.

It is probable that by the time Mayan architects were successfully handling appreciable side-thrusts they had developed good masonry techniques and that the outer walls would have supported heavier stable vaults. Where there are interior walls, calculation of heavier loads there might prove this. If this is granted, instability resulting from the factors under consideration would only raise the index (make it heavier), not reduce it. In any case, a light building of unknown vault design could still be considered as more advanced than a heavy one known to have stable vaulting.

A reverse handling of the above architectural elements may be occasioned by esthetic considerations, and such handling increases the load and so tends to increase wall thickness and reduce spans, as follows:

c.

d. A "negative batter" on the upper zone increases the load on the outer wall. (This term implies that the upper zone leans outward, the half-vault becoming correspondingly more bulky. (Fig. 8). But such an effect must be slight. It reduces (also slightly) any tendency toward side-thrusts.

e. Setting the base of the upper zone in front of the plane of the outer wall surface, on the overhanging medial molding or cornice) has the same effect, also not great. For convenience, we may call this treatment an "outset" upper zone. (Fig. 9).

f. Increasing the steepness of the soffit slopes increases the load, since, to a given span, the half-vaults rise higher before they nearly meet. This effect may be very great, yet be occasioned merely by an esthetic desire for a very high upper zone, or to give maximum strength at the center of the roof; in order to support an ornamental construction there (roof comb). (Fig. 10). Fortunately, such vaults leave evidence behind, even after complete collapse, in the form of very deep debris on the floor. Thus, even if the vault cannot be reconstructed and the actual load calculated, if the debris is very deep, it is practically certain that the index, as a time-counter, is too "heavy", and not too light. And wall-span comparisons between similar buildings should be valid.

A steep vault is equally more stable with a flat one, if the upper zone is vertical, but if the latter is sloping, is less so, as we have seen. Possibly it may happen from necessities of masonry (cohesion of the mortar) that a steeper soffit slope must be used to bridge a wider room, with a thickening of the wall to allow for the resulting higher and heavier vault (Fig. 9). If such were the case, the steepness of the slope would be a function of the room width and would not affect the validity of the index. In such buildings the steepness may be termed "necessary." (Fig 3). In general, steep soffit slopes would seem to be "necessary" only where spans are great.

Steep vaults of this sort will not add greatly to the depth of debris on the floor, since a wide room presents a greater area to receive it. This fact is confirmed in one instance at Piedras Negras (Str. J-11).

g. If the vaults are perforated with many openings, or have a great many deep niches let into them, they are of course, made much lighter. Such an arrangement, if present in outer half-vaults, would reduce the amount of side-thrust, if present, and reduce load on the wall. In such a case, the same load might be carried, and the same thrust resisted, by lighter walls. But the resulting lighter index would still reflect an advance, though it would be in economy of material, and not in reducing margins of safety for stability or load, or in improved masonry technique. For this reason, plus the fact that he knows of no cases of outer half-vaults thus treated, the writer feels justified in eliminating this arrangement as probably affecting outer wall-span relationships. It does occur at Palenque in balanced half-vaults over medial walls, greatly lightening their loads and thus reducing the necessary thickness of these walls.

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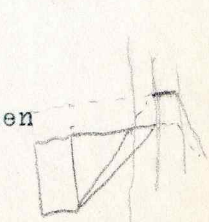
This would tend to lower a special index for interior walls, or an index reflecting all walls, but, as stated, a technical advance would still be indicated. Failure to allow for such openings could only lead us astray in saying how the advance was made.

h. The use of cap-stones (almost universal) reduces both load and tendency to side-thrusts. The wider the exposed surface of cap-stones (distance between tops of each half-vault), the lower and therefore the lighter ~~the vaults~~; and the less overhang and ~~consequent instability~~. Use of wide cap-stones should thus tend to reduce indices, not to increase them. As between very wide cap-stone exposures and their entire elimination, considerable differences in load and stability may be occasioned by this factor. But halving an exposure of 50 cms., which is probably close to the maximum will, for a moderate soffit slope of 28 degrees ~~(about 9 inches~~ from the vertical, only increases the vault height about 22 cms (about 9 inches). Failure to properly allow for this factor when reconstructing fallen vaults will therefore in most cases not lead us far

wrong — flatter vaults



astray in respect to the reliability of

astray in respect to the reliability of wall-span comparisons. In completely fallen buildings, the cap-stone exposure may be ascertainable by plaster lines on the fallen cap-stones, which mark the lines where the stone met the edge of the vault on either side.

In restoring fallen vaults on paper, a cap-stone exposure which is consistent with known practice at the site in other buildings of the same type should be used. It is possible that cap-stone exposures varies in relation to other elements of design. For instance, short exposures seem more logical with steep soffit slopes, and they would give a stronger roof to carry roof combs. But such relationships could only be established by comparisons of large numbers of known examples, and would probably be valid only within certain districts, as esthetic effects are certainly modified by variations in this element. Where there is no clue whatever, an assumed cap exposure of 25 cms would appear safest, as being the mean between no exposure at all (which occurs occasionally) and a probable maximum of fifth centimeters.

Flat concrete roofs resting on beams running from wall to wall were known to the Maya, at least at a late period. In the supposed advance toward wider rooms the architect might logically have replaced cap-stones with wooden beams. By making these beams longer than was possible with stone slabs he could have greatly increased the cap exposure and attained a much wider room for the same wall-span index or he could have reduced the index for a given span by keeping the vault-height down and eliminating side-thrusts. Such a building would be a combination of two techniques of roof construction--masonry vaulting and flat beam-and-concrete.

In the opinion of Dr. J. Alden Mason, who excavated it, and of the writer, there is such a structure at Piedras Negras (Structure P-7), discussed in some detail below. Failure to allow for such a roofing method (probably very rare)

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might lead us entirely astray in calculating probable loads and side thrusts on the walls. But the resulting light index would still truly indicate relatively late date, at least in a general way. This follows from the face that the single known case where this construction was probably used, it is known that complete vaulting technique was already well advanced. This instance is not one of moving from flat roofs to completely vaulted ones, but the reverse.

i. Of course, the greater the thickness of the roof-cap which was placed over the vaults and the cap-stones which usually connect them, the greater the load, and in some cases perhaps the greater the instability and consequent tendency to side-thrusts. If a roof-cap is excessively thick, it is logically possible that it was made so merely to gain a high upper zone in the facade, for esthetic purposes, with a consequent heavy effect on wall-span ratios. (It is the writer's impression, however, that variations in roof thickness) unfinished sentence

j. High walls offer less resistance to side-thrusts, if present, than low ones (Fig. 7). In series of buildings where side thrusts exist, or may have existed, a high wall (high vault-spring) would tend to be made thicker in order to meet the thrusts. The higher the wall the greater the load on the bottom courses. The presence of markedly high walls then, would tend to make the index "heavier", but not lighter.

k. The presence of piers in the facade--sections of wall between closely spaced multiple doorways--imposes no more load on masonry than occurs at the jambs of isolated doorways. However, if the vaults are unstable, perhaps the pier is less able to resist side-thrusts. The masonry forming a door jamb must meet the thrust of the vault immediately over it, plus the thrust over one-half of the doorway, transferred through the lintel to the jamb. Although the pier is nothing but two door-jambs brought close together, they are not anchored to long solid walls which meet only a normal amount of thrust. This is probably a matter of minor importance. So far as it would have any effect, the use of piers would tend to make the index "heavy", never the reverse.

Roys, 1934, note on p. 51

l. The greater the doorway width the greater the load on, and the side thrust (if any) to be met by the masonry at the jambs. Each must do one-half the work of the section of wall which has been left out to form the doorway. This fact was recognized and allowed for by better masonry at door-jambs. Wide doorways, therefore, represent a theoretical advance, and might tend to keep the index heavy, never the reverse. But doorway widths can only be compared if lintels are of the same type. Wider doorways can be bridged with wood than with stone. Yet stone may be preferred because of its permanency, or for other non-structural reasons, at a time when wider wooden-linteled openings were possible. The limiting factor on doorway widths was probably lintel strength rather than load or thrust on jambs. The effect of this factor on wall-span dimensions was, therefore, probably slight, or nil.

m. The use of small square or round columns (as distinguished from piers, which are merely sections of wall) increases the load enormously. This is especially true where they are used in multiple range buildings to carry beams supporting inner balanced half-vaults. Where used in the outer facade they

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are especially ill adapted to meet side thrusts. From the point of view of either stability or strength, therefore, any building making full use of them is probably to be considered far more advanced technically than one which does not. Comparisons of wall and span dimensions between such disparate buildings could hardly mean anything, though actual calculations of loads might be comparable Possibly an index showing the ratio of the column thickness to the vault-span might be significant when applied only to buildings using the column.

This element, at least below vaults, occurs in but few sites, and probably only in the latest periods of those.

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n. Pillasters or buttresses within the rooms may help to support the vaults and so lighten the load on the walls, and decrease side thrusts, if any. Their presence might allow an otherwise impossible reduction in the wall-span index, not the reverse. Thus, if they are associated with a heavy index instead of a light, one should look for high steep vaults or roof combs, as the probable reason for the massive construction, rather than an early date. (Structure 20 at Yaxchilan, Fig. 25). If associated with a light index they are probably doing their share to make a wide vault possible without excessively thick walls. In some cases careful examination may show that buttresses are secondary and non-functional. In such cases of course they have no effect on the index. To avoid misconceptions from reading ground plans, sections, and elevations, secondary or non-junctional features should be distinguished in the drawings, or described in the text.

o. Transverse partitions, cutting a long vault into small rooms, have the same effect as buttresses, as do the outer end walls of very short chambers. Short rooms therefore tend to permit a lighter index. But transverse partitions, like buttresses, may be secondary or non-functional, or both, and this is especially likely where they are very thin.

p. Beams running across from half-vault to half-vault (Fig. 1) will not affect the load on the walls, but if the vaults are otherwise unstable, might reduce or eliminate the side-thrust. If stability of the vaults was the limiting

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Roys, 1934, pp. 50-51.

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factor, it is possible that the use of such beams may have made a reduction in the index possible, but not the reverse. Since vault beams seem to be nearly universal in stable as well as unstable vaults, and both types are found standing after their decay, it is probable that this factor may be safely disregarded as selectively modifying wall and span dimensions, especially where vaults are stable without them.

q. Roof combs--ornamental constructions on the center line of the roof, or straddling it, if they are placed over a room, of course add both to the load and the tendency to side-thrusts. Where combs are present in this position, and appreciable in weight, the wall-span relation must be heavier than would be otherwise possible. (Fig. 10). But if they are placed over an inner wall and entirely supported by the balanced half-vaults on this wall, no side-thrust will result and no extra load will be transmitted to the outer walls. (Fig. 7). In such cases there is no necessary effect on the outer wall-span index, (unless wind-pressure on the comb was allowed for) though there is likely to be on an index reflecting the inner wall thickness. In any case, roof combs would affect wall-span indices in only one direction--tend to make them heavier.

Where the building has collapsed, a roof-comb, like a high vault over a narrow room, will add to the amount of debris forming the resultant mound.

Vaults may be high and bulky merely as the result of roofing a wide room with a practicable soffit slope angle, and the debris on the floor may be expected to be a little deeper where the span was great. But with a wider room there is a greater area in the room to hold the debris and such differences are probably not great. Since, with a given standard of technical and theoretical knowledge, a short span can be bridged with less material, when deep debris deposits are found over the floors of narrow rooms, there is a strong probability that the extra debris, unnecessary for meeting the mere problem of roofing the room, comes from an unnecessarily high and steep vault, or a roof comb, or a combination of both. Stated in another way, if two entirely fallen buildings are compared, each having the same room width, but the debris in the first is twice as deep as in the second, the first probably had a high vault or roof comb, or both, the sedond not. Their presence in the first example would call for thicker walls and a higher index, or buttresses, partitions, short rooms, or all together, although both buildings may have been contemporary.

The maximum and minimum depths of debris over the floors of fallen buildings should, therefore, be carefully noted. When used with an eye on the actual room width, it may in some cases be possible to say with assurance that the wall-span index of certain buildings is heavier than was structurally possible at the time, had high vaults and/or roof combs not been desired for aesthetic purposes.

r. A "flying facade"--an ornamental wall placed on the roof, but over an outer wall, increases the load on that wall, and might thus raise the index on that side. An example of this is the Iglesia at Chichen Itza, where no such effect is discernible. Such ornamental walls are not very heavy and this factor

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probably has little importance. In any case it would operate only on the index involving the wall below it.

s. Placement of a second story wholly or partly over a vault beneath it, will operate like any other heavy construction on the roof, except that it is likely to be greater in amount. If part of the extra load falls over the lower room, stability will be lessened. In any case, the load on the lower walls is increased and a higher index would be expected.

t. Where excavation has not resolved the matter, the desire to use old walls as a matter of convenience, or to allign a new building with an old, or to make an addition conform with the original structure, may determine the wall thickness or room width, or even both. Two cases where this occurred at Piedras Negras are mentioned below (Room 1 of Str. J-6 and Room 6 of Str. J-2). This doubt may be eliminated by excavation if this is possible. And for probably the majority of buildings, merely reading the plan of the building and its environs will rule out this possibility. If a building stands entirely free of other buildings and substructures, and the plan is a logical whole, it was probably erected at one time, and without reference to wall and span dimensions of other buildings.

This factor can operate only to make a building more massive than it otherwise might have been, by keeping walls thicker, or rooms narrower, or both, never the contrary. The presence of old walls might concievably suggest the erection of a more advanced unit, but would then be merely the motive for the advance indicated by the index.

u. Mere spacial limitations of the site may effect the room width. This factor may operate in connection with the use of old walls, but in any case, has an effect in the same direction--to narrow the rooms. It could not have the effect of thickening the walls, but on the contrary, would give an added motive to thin them, in order to make maximum use of available space. Where spacial limitations are suspected, the direct comparisons of the outer wall thickness are probably the best guide. Where the wall is thinner than is common at the site for buildings of similar indices, the index is likely to be heavier than was structurally possible.

Where the plan shows buildings standing free of others, with plenty of room either to the front or the rear, there is little reason to suspect that limitations of space have affected the index.

v. Function may interfere with an orderly advance in design from a structurally possible point of view. Thus it is possible that religious conservatism might keep a temple relatively massive at a time when architects were free to go the structural limit with palaces. There seems to be no structural reason for the extremely heavy construction of the front parts of the famous Temple I to V at Tikal. For this reason, the surest comparisons will be between buildings of similar function--to be determined in our present state of knowledge by similarity of plan, position, and interior arrangements. This is merely to say that wall-span dimensions or ratios, even after the hurdles listed above have been eliminated or jumped, may still mislead us when they are used to lock two series of buildings together, the series comprising buildings of differing function.

With such a list of disturbing factors staring us in the face, some of which may work in one direction, others in the opposite, in various combinations and all on one building, wall-span comparisons should be made only with the utmost caution. They should always be checked with all other available chronologic criteria, and immediately suspected if they do not agree. This means each site should be studied as a whole. Not only may inscriptioned, ceramic, and other architectural criteria be brought to bear on the dating problem of a building, but such matters as objects cached in the floors, the types of altars permanently fixed in them, or types of associated buildings. And they should be applied to as many structures at each site as possible. If it is possible to show for a number of buildings that these extraneous factors cannot be made to account for observed variations in building massiveness, a chronologic interpretation seems to the writer reasonable secure. It is especially so if other criteria are in agreement. If such a development in time has been proved for the site, it is much less dangerous to accept chronologic significance for the indices of a few buildings where extraneous factors remain unknown.

To make analysis of the buildings discussed below more easy, the disturbing factors discussed above are set down in the check-list forming Table 1, but in a more convenient order, based on their effect on wall and span dimensions.

The first nine--high vault springs, roof combs, columns, use of old walls, thick roofs, use of piers, wide doorways and flying facades--can operate only to retard the theoretical progressive thinning of walls and widening of rooms, and thus to raise the indices here used--that is, to cause the index to register too early a date.

The items ten to fourteen--pillasters, partitions or short rooms, vault beams, vault openings, wide cap-stone exposures, tend only in the opposite direction--to reduce the indices.

The next three, items fifteen to seventeen--sloping upper zone, flat vaults, inset upper zone, also tend to reduce the indices by eliminating weight except in cases where their presence on a thinner wall would leave too small a margin of safety in the matter of stability. In such cases they might lead to thicker walls or narrower rooms than would otherwise have been possible.

The amount or force of these factors, separately or in combination, can, of course, only be calculated from completely known cross-sections. Where this can be done, the best indices of progress would be actual loads per square inch, and the actual margin in pounds of force per unit of wall, between actual side thrusts and those necessary to cause wall collapse in each building.

It appears to the writer that lack of knowledge of quantitative measure of side thrusts is the most likely source of error in the interpretation of wall-span indices. This applies especially to buildings where side-thrusts are of considerable amount are actually present, and the indices are most likely to be wrong chronologically where these ratios differ least in amount. The reason for this special danger is the fact that great side-thrusts are most likely to result from flat vaults, sloping upper zones, or inset upper zones, especially the three combined; and the fact that, if vaults are fallen, no trace of their former presence is left in the debris. Such vaults in themselves represent an advance in economy of material. But they tend to raise wall-span ratios, in order to allow for the large thrusts and thus to hide this progress, or to actually record a non-existent regression, where we have only the walls and rooms as a guide.

The indices may in such a case be valuable, nevertheless. If large thrusts are suspected only in a group of lighter buildings, proper allowance for them would only show, if anything, that the gap between the two groups of indices was too small. It would not vitiate the indication that the lighter group is the later. Likelihood of error on this score only enters when the unknown thrust-producing elements may have occurred in both groups under comparison, or in the heavier group.

It appears to the writer that even where factors such as sloping upper zones, flat vaults and inset upper zones occur on relatively heavy walls, they may be safely disregarded if it is known that the vaults were nevertheless, stable. It is improbable that an architect would thicken his walls, or narrow his rooms, in order to resist a non-existent thrust. A thick wall (unless it is very high) would appear to have an adequate margin of safety for stability until the combination of factors in vault design which tend to produce thrusts were strong enough to move the center of gravity of the half-vault out over the room. If this has not occurred, their only probable effect would be to lighten the vaults and permit a thinner wall or a wider span. If the wall is made thinner on this account, or the span increased, the load per square inch on the wall might remain the same; but the resultant lower index still represents progress-- in vault design rather than in masonry technique.

Items eighteen to twenty--unnecessarily steep vaults, negative batter on the upper zone, outset upper zone--tend to increase the indices by adding to the load. They have a stabilizing effect, and from this point of view tend to reduce the indices. But in the first of these three factors this stabilizing effect is ruled out as a disturbing element by definition. If the steep soffit slope is for purposes of stability, it is either balanced by another element of opposite effect, such as a sloping upper zone, or it is caused by the great width of span in relation to wall thickness-that is, it is one way among others of achieving the advance reflected in the index. By "unnecessary" in the table, we mean that this was not the case.

Space limitation and function (items 21 and 22) are put last because they have no relation to structural possibilities, although they may affect the dimensions in question. Space limitation furnishes an added motive for reducing wall thickness and therefore the index. If this does not happen to a sufficient degree, stability will be raised, but only incidentally. This factor could operate, it seems, only to raise the index by keeping the rooms narrow. This effect may be partly or wholly negatived by thinning the wall. Differences in function might keep the index of one building heavier than another. But when thought of in relation to the lighter building, it would be merely a motive for the structural advance.

In the check-list (Table 1) we have, for convenience, listed these plus or minus effects on the indeces in three columns. The first two suggest the probable effect on the stability, of, then on the load carried by, the outer wall. The third column indicates the probable effect on the load carried by interior walls supporting balanced half-vaults. Finally we have indicated after a number of factors the probability that their effect either way is slight.

Before examining walls and spans of a number of vaulted buildings at Piedras Negras and Palenque, it might be well to point out that all the buildings to be compared must be known to have been vaulted.

This fact can be read from a plan only when the room width is so great, or the wall thickness so little, as to be incredible in a vaulted building in the area in question; or where believable thicknesses and spans are so combined as to yield an incredibly low wall-span index. We cite unpublished examples of the first and last of these possibilities from Piedras Hegras:

Structure K-5-3d, excavated in 1932 by Dr. Mason, is a single chamber temple yielding a wall-span index of 22 per cent, which is only one point below that of Structure F-4, a surely vaulted building. The front wall thickness is 1.10 m but its span is no less than five meters. Surely no such wide vault as this was built in the Maya "Old Empire" yielding the "late" index for a building two periods earlier than the heavy vaulted temple K-5-1st above it.

Structure V-1-2nd illustrates the last, perhaps also the second, possibility. The span is 2.60 meters, known to occur elsewhere at the city among vaulted buildings. But its wall is only 35 cms thick. This might possibly be used in a light and small vaulted, but not in combination with a wide span which yields an index of only 13 per cent.

At the other end of the scale, evidence from the plan alone fails entirely. While it may be admitted that heavy walls and narrow rooms were a necessity in vaulted buildings, until vault techniques were advanced, they were used in non-vaulted buildings, and therefore for other reasons. What those reasons were, and whether wall-span ratios have dhronologic significance when applied to non-vaulted buildings is outside the scope of this paper. The following instances of very heavy indices in buildings at Piedras Negras, proved to have had non-vaulted roofs by excavation, will establish the point that heavy buildings may have been non-vaulted.

Structure U-3, which is double-ranged, has outer walls 1.20 meters thick, a medial wall 1.50 meters thick, and rooms 1.70 meters wide. The resulting outer wall-span index is 71 per cent. Structure R-3 is a single chamber temple, the front wall 1.30 meters thick; the rear wall is collapsed but also very thick. Yet the chamber is only 1.50 meters wide. The front wall is the thickest known at the city and the outer index for the point the heaviest--87 per cent.

Where buildings are entirely collapsed the former presence of vaulted roofs may be detected in a variety of ways, not all of which are available everywhere.

The most universally available test is the quantity of debris on the floor. A vaulted roof forms much more debris than a thatched one and to a somewhat lesser degree, than a flat beam-and-mortar roof.

Cap-stones are almost universal and their presence, if identified with certainty, proves the point. In the Usumacinta region, and probably generally, they are long thin slabs, with the long sides more or less parallel. Morris reports them as of a specially hard limestone at Chichen Itza.

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Where vaults are faced with blocks, the faces beveled to follow the soffit slope, they will be present in the debris and tell the story. They occur at Copan, at Yaxchilan, and doubtless elsewhere in the "Old Empire". In northern

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Yucatan they are further specialized into boot-shaped "boveda" stones. But their absence can hardly be relied on, unless confirmed by other criteria. While present in the Yaxchilan building cited, they are absent in many if not all others at that site.

Where, as is usual in the Usumacinta and at other sites such as Naranjo in the Peten and Coba in northeastern Yucatan, the vaults are faced with slabs

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but roughly worked, these will be found in quantity, especially near and on the floor and they will be mingled with much disintegrated mortar. Often a number of slabs will be found more or less flat against each other, or actually still cemented together as they were in the vault. They will be found on edge, at various angles, and in horizontal positions. If slabs are present in quantity as indicated, they come from a fallen vault unless the walls themselves were largely built of slabs. In such a case, if a vault was not used for the roof, the number of slabs and the quantity of debris generally may be expected to be less than is usual, and mortar will probably be less in evidence. In doubtful cases, standing portions of walls should be examined as possible sources of more of the material found on the floor.

Fallen vaults tend to leave a debris deposit light in color, especially toward the bottom, due to the large quantity of mortar in the interior of the vaults, and in the roof-cap, and to the debris depth which, after the collapse, protects the lower portion from the darkening effect of decaying vegetation. This is so at Piedras Negras, at any rate. But beam-and-mortar roofs probably would produce lighter colored debris also, and this criterion is perhaps not reliable.

A thick layer of disintegrated mortar and small broken stone, lying beneath all stones suitable for use in walls or vaults has been interpreted at Piedras Negras as a probable sign of the beam-and-concrete roof. This was found in the massive temple R-3 mentioned above, which was excavated by Mr. David I.

Omram, Jr. of the University Museum's 1933 expedition. In a vaulted building, vault-facing stones (either specialized blocks or of slabs many of which are of some size) are bound to fall to the floor before much roof material can have reached it, and many of them should be found in actual contact with the floor. In the case of a beam-and-concrete roof, the latter may be expected to drop to the floor first, as the beams decay, the wall stones falling on this layer latter as the walls gradually decay. Some slabs might of course be used in a flat roof, but their quantity would be small, and they would be less likely to be found on edge. The best way to study debris, if excavation is possible, is in cross section. If the side of the trench is properly prepared, its character can often be satisfactorily recorded by a photograph.

The contours of the debris, even before the floor level and consequently the depth was known, have been used successfully at Piedras Negras to predict the absence of vaults, before excavation.

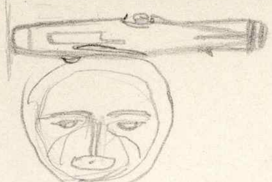
Where walls are of masonry but roofs are supported by beams (whether pitched and thatched or flat and capped with concrete) there are no thrusts on the walls. The roofs will fall in first leaving a relatively shallow deposit of debris. The walls then disintegrate gradually, except where a falling tree intervenes, and the debris tends to fall straight down, forming ridges and humps outlining the walls and piers respectively. With vaults, the collapse is more likely to be sudden, with outward movements of the upper parts of the walls and piers as the vaults fall inward. The mere quantity of debris tends to obscure the ground plan. It is of course possible to follow the ground plan in many vaulted buildings, where the walls and piers and portions of the vaults actually protrude through the debris. But where they do not do so, the plan cannot be followed under the more or less rounded contours of the mound. On the other hand, in four cases where the plan could be so followed, no actual masonry was visible and excavation eliminated the possibility of fallen vaults. The converse is not true. We have dug in mounds of non-vaulted buildings which yielded no clue to the plan. One of these was Str. R-3, which presented an unusual amount of wall material, and a narrow chamber to hold it. But another

It is a combination of the above criteria which led us to believe that Structure P-7 at Piedras Negras, mentioned above, must have had a combination of vaulted and flat beam-and-concrete roof. The span, 3.70, is possible but greater than anything else known to have been vaulted in the three principal cities of Usumacinta area. On remaining vault remnants, the soffit slope was steep, (22½ degrees) and if restored to the height necessary for cap-stone exposure of 50 cms., they would have been unstable in the extreme. They were combined with inset upper zones and walls higher than anything else at Piedras Negras. Front doorways were 35 cms wider than any other at the city, yet their lintels would have had to carry heavier half-vaults than any others. These factors of design need not have been introduced, yet they made such an ambitious vault, difficult anyway, more difficult. Negatively, the architect did not introduce pillasters or partitions, and the rooms were long, and there were no beam holes up to the (so far as known) vault height of 1.25 meters, any of which might have added to stability. The outer walls were not particularly light (cms thick) and yielded an index higher than others at the city. However, this might be a function of their greater height. The design, then, was such as to add weight to the suspicious wide span. The debris, we think, gives the proof.

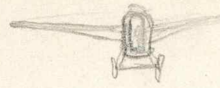
The debris was entirely too small in quantity for such a large and high vault. No cap-stones were observed. In the center of the right end of the front room (the left end was not excavated) there were no vault slabs whatever. This was presumably, because here the balanced medial half-vault still stood to its original height. The front vaulting apparently fell almost entirely outside the building due to settling and outward lean of the front walls. A complete half-vault of the required height must necessarily have fallen in on the floor. At other points where vaulting slabs were present in the debris, they lay over a thick deposit of crushed lime-stone and mortar which included a few small slabs, unsuitable for vaulting purposes. And they were too few for a fallen complete vault.

All of these indicated what was already suspected--that the vaulting, where it had not fallen entirely, had not, in large measure, fallen at all. This was confirmed by a fairly level surface on the top of the right unit of balanced medial half-vaults; and especially broken thin slab-like fragments of hard concrete, of mortar and river gravel, the latter unknown ~~elsewhere~~ in vaulting mortar. These were found in larger pieces, with a smooth plastered finish preserved on one side, immediately on or close to the floor on the center line of the front room, at both cross-sections examined. River pebbles from such a concrete plastered element--(obviously the roof surface) were found on and close to the floor wherever the debris was examined. By no stretch of the imagination could a completely vaulted building so collapse as to spread its roofing material more or less evenly on the floor; and on the newly exposed surfaces of the lower parts of its vaults after the tops had fallen off.

The writer has summarized this unpublished data, with the kind permission of Dr. Mason, who has its proper presentation in preparation, because he believes the building at present is unique, and has its importance in reconciling negative debris tests for fallen vaults with vaulting actually to be seen on the walls. If this technique was ever used on narrower rooms, or lower walls the wall-span index might be very greatly reduced below the limit possible for completely vaulted rooms. The practice seems to be an advanced one in itself. Like the mansard roofs of Palenque, it eliminates roof weight, but without consequent side-thrusts and here permitted a wider room than anything thus far known there. An included nicely vaulted central sanctuary rules out the possibility that this building represents a transition step from flat toward vaulted roofs. The outer wall-span index of this sanctuary is not the lightest in the city (there is a doubtful one of 18 and a sure one of 23 per cent.) But it must be discounted for several factors: possible desire to economize space; possibly function; and it supported a second story of considerable weight, almost certainly of the same semi-vaulted type as the principal rooms. This vaulting was designed on the balanced half-vault principle on all four sides, which added considerably to the weight. The index of this little single-chamber unit is, therefore, insufficient to dispel the suspicion that this building is one of the last in which the vaulting principle was used at the site.



Religions



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Plains

War normal - movements to follow seasonal trek of buffalo.

- Coup - military exploit represented by a feather in the headdress.

More honorable to wound than to kill

- to do it with a knife instead of a gun.

Horse stealing was honorable - clashes with settlers.

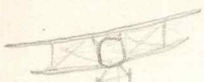
Tepees in circle for defence - rudy [illegible] mounts also lived almost in saddle.

"Police" - guard on the job - "dog soldiers"

- camp always under discipline

Highly organized for war - not otherwise

- no sibs or gentes
- No tribal organization e.g. with the 4 independent bands of Arapaho.



||| Ritualism probably more highly involved than any other part of the world.

Majority of rituals were public - quest for supernatural - but source of them less important - (function of the societies?)

"Bayaanwu" - series of dances based on age groups (1 exception).

Males divided into age classes - members moving up

- 1st Kitbox lodge - puberty up to 18.
  - whistle + sage (the regalia).
  - lodge itself of brush, with center pole.
  - the dance had no characteristic action.

(all members participate in dance)

2nd Star lodge.
- Membership in this purchased from members.
- 18-25 in age.
- regalia - the rattle.
- no lodge, no characteristic action in dances + ceremonies

3d Tomahawk.
- By membership.
- age 25-30
- No regalia
- Skin lodge.
- characteristic action in ceremonies - racing.
- dancing restricted

4th Biitahanwu Lodge

membership bought by graduating members of Tom. Lodge

Age - 30-40.

Regalia - lance
Belt
feather at occiput.

. this group has to do with crises.

Skin lodge.

Char. action dancing + racing.

no. of dancers restricted

5th ______ Lodge

Age. 40-50.

Regalia
whistle
cape
feathers at forehead.
Skin lodge.
Ch. action;
dancing
fire standing
extravagance.
No dancers restr.

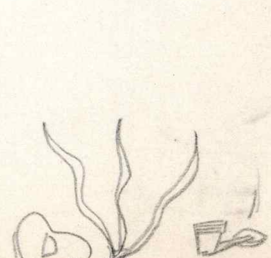
6th Dog Dance Lodge.

50-60 age.

Reg. whistle
rattle
scarf.
Skin lodge.
ch. action: dancing
painting body.

7th Hinanahanwu Lodge.

Age 60-70
Reg. - rattle
- rope (?)
Skin lodge
action - singing, dance



8. Water-Sprinkling Old Men Lodge.

Og - over 60
- Reg. rattle
Lodge - sweat house
Ch. action:
Singing
Sweating
- usually dive into cold water on leaving the sweat house.

Womens Lodge
- all females belong
Reg - whistle
Buffalo headdress
Belt
Lodge - skin with center pole
action - Dancing,
Racing
Representing buffalo

Each lodge has characteristic dances.

For some lodges - diff degrees within L.g.

Tomahawk.
a - Reg, sword, ch. color black. (highest)
b - " sword, color red. (3 parts)
c - " Tomahawk, color red + white (lowest)

white
black red
yellow

Bi-C4W
a - regal - club
" - crooked lance wrapped with fur.
b - - otter skin lower blue of color
c - - straight fur wrapped lance
e - - boys lance, color black
- headed lance, color black
f - red one of two-circling lance, color red.
f -

5th a – white. – cape + bow

– " ", red + white ~~

Dog Dance Soc.

a – feather covered coat,
crow feather instead of color

b. – Reg. scarf, red color.

c. – scarf, yellow color.

e. – upright feather headdress – turkey feathers
in lieu of color.

Womens:

a – Reg. – Swansdown, buffalo headd. – white

b. " " – "

c – standing feather headdr. – red color

d " " white "

e. Buffal headdres, white or yellow.

Everything a plains Indian uses is symbolic of his status.
Religious ceremonies involved with all these groups.

e.g. must have a vision to get in 1st lodge – goes out + fasts
till he gets the vision.

4th – Biikahan – the lodge for crises:

– e.g. in sickness – make a vow to give a ceremony. Goes to
members ~~to~~ to become dancers (will ask those with all degrees.
They take charge of certain parts of ceremon.
– also goes to old men – who are appointed to make the regalia
required for the cereny – paint the dancers, etc. – to guide ceremonies
in preliminary stage. They are paid in horses, tipis, food, supplied by
giver + his friends.

"Stout men
north

arrangement in lodge, theatrically erected. {

"Grandfather (west)

Dancers of high

South
(Short men – dance)

(Dancers of higher rank at west end of line)

Leading grandfather brags; recounts a war exploit; then presents the regalia, and they prepare to drench the dancers. –
Rub them with a root medicine, then drench them.

Then preliminary ceremonies begin (3 days)
1st Pledger takes a split willow stick, places a coal in the end, has old man who puts sweet grass on it – censes the drums.
Singers (band) appears to take charge of songs.
West end of line joins dance first (acc. to rank).
Dance from right to left around lodge (pledger leads.)
Then race to stop in east end of lodge, & back. Last is pelted with buff. dung.
Grandfathers then retire.

Ceremony proper – 4 days.
– dancing at night & before sun
– 2 tents – 1 for "short," one for "stout" men, at opp. sides of the camp circle.
Dance followed by race between tents.
Dancing to leaders tents on (1st) NW; SW, SE, NE. (leaders
| tents are located to points of compass.

are there 4 chiefs?

Each chief has symbol painted on his tent.

× 4 old men offer prayers.

Red paint - symbol of life -
spec. that children reach old age.

Yellow tips on eagle feather - sun light.

Every detail of weapon, wearing apparel, etc. is symbolic.
- In no ceremony of one cuises ceremonies.

Sun Dance - only one of large no of ceremonies of this Bi't lodge.
- Arapaho call it the "offering lodge - a part of Bi't Society.
8 - days.

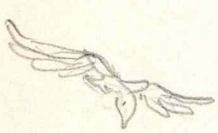
1st day Formal announcement, erecting "rabbit tent" - practices begin.

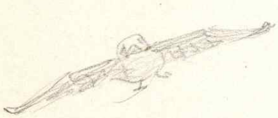
2nd 1st Preliminary day - participants in rabbit tent - songs, rites - party send out for a center pole for main lodge - go out as if as a war party. Great pomp as they leave - then scatter + continue till they swoop down on the tree. Formerly a party had to go out for buffalo - later use only a skin.

2nd - more in Rabbit tent - Sweat house built + used. Party goes out for rafters for lodge.

3d - Center poles in attacked + felled, This is an exploit as if it was a dead enemy. Pole brought home with great rejoicing.
Robbit tent abandoned, new lodge poles painted, lodge erected.

Dancing that night. Start to fast. (partial





Main Ceremonies

4th Sods cut + used to form an altar. Dancers painted + formal dancing begins.

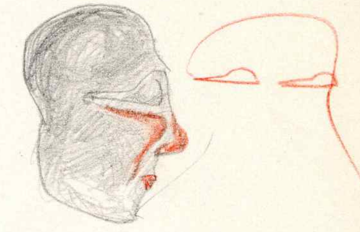
5th -

6th Torture element - a minor part of ceremonies as a whole.
- But has resulted in outlawing of the whole dance.
- participants have not eaten or drunk for 3 days.

thongs from pole pass thru muscle of chest, almost suspending him. Others through back to suspend buff-skulls. Must dance till thongs pull through.

Fast broken at end of this day, sacred water is drunk - the ceremony is over, except:

Supplementary day of dancing out of the participants. Worn clothing of children is burned on altar.



No priesthood (organized) - old men may vary.

No church.

Beliefs are unimportant to the Indian -

Form is outstanding importance.

Sun dance - dancer faces the sun.