ORTHOPHOTOGRAPHY AND ITS APPLICATIONS IN THE RECORDING OF BUILDINGS

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Ringkasan

Rencana ini menyentuh berkenaan dengan teknik orthofoto di dalam kerja-kerja merekod bangunan. Pertamanya, tumpuan diberi kepada konsep orthofotografi di mana prinsip rektifikasi "differential" dihuraikan. Bahagian kedua membincangkan selisih-selisih yang terdapat di dalam proses orthofotografi yang memberi kesan kepada ketepatan dan juga kualiti gambar orthofoto tersebut. Di antara selisih-selisih tersebut, selisih sistem mempunyai kesan yang terbesar kepada ketepatan dan kualiti gambar orthofoto dan diikuti oleh selisih "scanning." Akhir sekali, penulis mengemukakan beberapa perkara yang diperhatikannya dalam kajian yang dibuat ke atas empat jenis permukaan bangunan.

Abstract

This paper deals with the orthophoto technique of recording buildings. Firstly, it focuses on the concept of orthophotography where the principles of differential rectification are described. Secondly, the errors inherent in the orthophotographic process which would affect the accuracy and pictorial quality of the final product, that is, the orthophoto itself are discussed. Among the errors, system errors followed by scanning errors have the major effect on the accuracy and pictorial quality. Finally, the writer presents his observations from the studies carried out on four different types of building surfaces.

1. Introduction

The frequently used photogrammetric technique in recording buildings is stereoplotting. This technique has been found to be accurate and applicable to objects of any type, shape and size. The result of stereoplotting is a line map which shows the recorded object in the form of elevation and plan views. The efficiency of this technique becomes questionable if highly ornamented surfaces must be plotted. The recording of such surfaces will be time consuming and hence uneconomical due to the tremendous amount of details to be plotted. The orthophoto technique would be a better technique for recording such surfaces. Seeger (1976) estimates that the stereoplotting technique would increase the time required by a factor of 5 to 10 in comparison with the orthophoto technique for such surfaces. The orthophoto technique permits the portrayal of all the details, unlike in stereoplotting where a certain amount of selection of details has to be done by the photogrammetric operator. This is useful because the user, such as an architect or a conservator still has the opportunity of interpreting the details on the orthophotos according to his needs. In terms of accuracy, both techniques are accurate to about ± 15 mm in reference to the object.

2. Concept of Orthophotography

A photograph taken by a camera records a central projection of the objects imaged on it. In general, images recorded by such a central projection are not at a uniform scale due to image displacements arising from the photo plane being tilted with respect to the datum plane at the instant of exposure, and also arising from depth (elevation) differences in the objects.

The desire for a photograph of uniform scale led to the development of instruments for the production of orthophotos. An orthophoto is a photograph in which individual images are at a uniform scale and located in correct relative position to one another, as if the corresponding object points have been projected by an orthogonal projection onto the image plane. It is equivalent to a conventional line map or plan which also shows true orthogonal positions of objects. The major difference being that the orthophoto is composed of images of objects, whereas a line map or plan is composed of lines plotted to scale to depict objects.

An orthophoto can therefore be used as a map or plan for making direct measurements of distances, angles, positions and areas without making corrections for image displacements since it is planimetrically correct. This cannot be done with perspective photographs. Orthophotos are produced from perspective photographs through a process called differential rectification which eliminates image displacements due to camera tilts and depth (elevation) differences.

Differential rectification in a typical orthophoto equipment is carried out by a strip-by-strip scanning of the model area of one of the photograph instead of an instantaneous exposure as in plane or conventional rectification which eliminates image displacements due to camera tilts only (Fig. 1). By continuous change in magnification, the rectification scale is varied according to the height (depth) differences in the object. Differential rectification is further illustrated in Fig. 2. The shaded line represents the object profile. An orthogonal projection is obtained of the profile between P_1 and P_2 by projecting one of the photograph through the projection centre O. The projection plane in the stereoplotter is brought into position P_1 and at the same time the magnification corresponding to the projection ratio is set in the projection plane of the orthophoto component of the instrument via electrical connections. In this projection plane, a photographic emulsion is arranged. The light from point P_1' on the photo carrier of the stereoplotter reaches the photographic emulsion through a slit. This slit is made to move on the projection plane from P_1 to P_2. During this process, magnification is continuously changed so that the projection plane moves from p_1 to p_2. All points on the profile P_1P_2 are photographically recorded in those places of the projection plane which corresponds to the orthogonal projection $\bar{P}_1\bar{P}_2$. In this way, the height (depth) differences in the object become effective as a source of error in the range of the slit area only. Since the slit width is relatively small, these positional errors are usually small. With proper selection of slit width, these positional errors can be controlled.

3. Errors inherent in the Orthophotographic Process

Errors found in the final result (orthophoto) after the orthophotographic process, arise not only from errors in the process itself but also from errors inccured in ordinary photogrammetric restitution. This is because differential rectification by orthophotography is an extension of the principles of ordinary photogrammetric restitution. These errors can be classified into the following:

i) Restitution errors
ii) System errors and image movement
iii) Scanning errors
iv) Transfer (connection) and projection film errors.

3.1 Restitution errors

These are errors which arise from the accuracy of the control points; image errors such as lens distortion errors; film flatness errors; pass point errors; inner, relative and absolute orientation errors and errors arising from the geometric performance of the restitution instrument.

3.2 System errors and image movement

3.2.1 System errors

This is the source of error which has the major effect on the accuracy and pictorial quality of the orthophoto. These are errors unique to the orthophotographic process and arise due to the fact that the image transfer, for practical reasons, is not carried out on a point-to-point basis from the original image to the projected image.

The effect of these errors follow the tangent of the angular field α (Fig. 5). Normally, the image is transferred through a line element in the form of a slit with certain dimensions. If the dimension of the slit is denoted as $b \times \ell$ where b is the width of the slit in mm. and is the length of the slit in mm. (Fig. 3), then the slit dimensions available for example on a Zeiss Jena Topocart-Orthophot (Fig. 4) are 16x1, 8x1, 4x1, 2x0.5 and 1x0.5. Both ends of the slit are cut at an angle to provide blending areas so as to avoid gaps or visible overlaps between adjacent scanning strips (Fig. 3).

System errors occur, if the model surface at the slit is not horizontal. If the model surface is sloping across the slit width (Fig. 5), only the centre of the slit as defined by the measuring mark is at the correct elevation. Off-centre points are all projected at incorrect elevation and are displaced from their true position radially away or towards the nadir point. The maximum error ΔZ in elevation occurs for a point at the extreme end of the slit and is given by $\Delta Z = b/2 \tan \beta_x$ where β_x is the slope of the object surface in the slit width direction (x direction). The radial displacement Δr is given by $\Delta r = b/2 \tan \beta_x \tan \alpha$ where α is the angular field.

In the orthophotographic recording of certain buildings, there are long stretches of walls where a number of successive scans can be made with the wall surface lying horizontal or nearly horizontal to the slit (Fig. 6). In such a case, system errors would be minimal. But there are always parts of buildings with sudden changes in depth in the slit width direction. In such cases there will occur system errors which may cause gaps (details are missing) and double images (details are imaged twice). In Fig. 6 scans 1, 2, 4 and 6 do not possess system errors and details contained within them are projected correctly but scans 3 and 5 suffer from system errors and not all details contained within them are projected correctly.

System errors can be reduced by using a smaller slit width but scanning time and stress to the operator will increase accordingly.

3.2.2 Image movements

Theoretically, slopes or change in depth in the direction of scan (y direction) should produce errors in the position of the projected images. Since the length of the exposure slit is very short, the error is insignificant. For a slit of finite length, the correct height can only be set for the centre of the slit. An image is produced at the front and rear edges of the slit, although the respective objects are hence not yet in their correct positions. This correct position is obtained only when they are produced in the centre of the slit. As a result, there will be a certain amount of image movement given by the equation

$$W = \ell \left[\frac{\tan \alpha_y - \tan \beta_y}{1 - \tan \alpha_y \tan \beta_y \cos \gamma} \right]$$

where ℓ = length of slit

α_y = angular field in the model YZ plane

β_y = slope in the scan direction

γ = radial direction in the XY plane

Meier (1966) shows that 0.4 mm is the largest displacement which may be tolerated due to image movement and that this falls inside the plottable model area of a 23 x 23 cm. wide angle photograph in the case where a 1 mm. slit length is used and the ground slope in the scan direction is 25°. Image movement can be reduced by selecting a shorter slit length or reducing the angular field. The formula quoted for determining image motion is not suitable to be applied directly for buildings since the slopes in the scan direction change abruptly and frequently unlike in topographical mapping where slope changes are gradual and not so frequent.

3.3 Scanning errors

Scanning errors result from the fact that the photogrammetric operator cannot keep the measuring mark in perfect contact with the model surface all the time while scanning in the y direction. Next to system errors, this is the source of error which has a major effect on the accuracy and pictorial quality of the orthophoto. On a flat surface such as a horizontal wall, the depth error ΔZ produces a radial displacement Δr from the nadir point proportional to the angular field α i.e. $\Delta r = \Delta Z \tan \alpha$ (Fig. 7).

Meier (1966) has shown that in orthophoto mapping for topographical purposes, in the case of sloping terrain, the error in Z is made up of two components. One component is a constant error C_c equal to 0.1 °/oo Z which expresses the fact that vertical errors must be expected even when the measuring mark is stationary. The second component is dependent on the scanning speed V_B, the relief in the scan direction β_y and a certain interval C_t which is equal to 0.16 sec, being the time required to convert the visual stereoscopic information into the appropriate ΔZ correction of the measuring mark. This concept can equally well be applied in analysing the errors in orthophoto work on building surfaces. The height or depth error is given by $\Delta Z = V_B C_t \tan \beta_y + C_c$ and the corresponding planimetric displacement is $\Delta r = \tan \alpha (V_B C_t \tan \beta_y + C_c)$ (Fig. 8).

Scanning over surfaces which have a substantial and perpendicular change in depth will be quite problematic (Fig. 9). While scanning along AB, the operator will raise the measuring mark at B only to reach the top surface CD at D and not C. B'' and D'' are the correct projection of points B and D onto the projection plane. Any point between C and D is not projected correctly onto the projection plane. To reduce scanning errors in such surfaces and other difficult parts, a slow scanning speed and experience in driving the measuring mark are important. It is dependent also on adequate acceleration or delay of the measuring mark on the stereoscopic model and the location of the rectified elements with respect to the projecting plane and the projection centre. This is illustrated in Fig. 10. In Fig. 10 (i), the measuring mark is raised at A so as to reach C, because it is more important that point C be projected correctly than point B. It is also important that the mark should be at D exactly as compared to E because point E is 'hidden' by D. But F is not 'hidden' by G and hence the measuring mark has to be brought quite close to F, but not too close, so that it can be raised in time to be brought to G.

In Fig. 10 (ii) the measuring mark has to be brought much closer to H then at L since it is much closer to the optical axis of the projection camera than L. Since points H and I are equally important, there has to be a compromise in raising the measuring mark and as a result point I would be projected incorrectly by a small amount. At J,K,L and M the situation is the same as at D,E,F and G respectively.

An important point to note in using such a method of scanning is that its consistency from one scan to the next is imperative for a presentable final product. In scanning over a similar kind of surface the delay or acceleration in raising or lowering the measuring mark has to be quite the same in adjacent scans. Also the point at which the mark is raised or lowered has to be quite the same (Fig. 11). If not, there will be displacement in the images.

3.4 Transfer and projection film errors

Transfer errors do not occur in instruments such as the Bean Orthophotoscope since the film is in the model space. But in instruments such as the Wild A8 PPO-8 and the Zeiss Jena Topocart-Orthophot such errors occur. This is because there is a possibility that the optical and mechanical system are not correctly calibrated and aligned so that the measuring mark position coincides with the centre of the exposure slit while scanning takes place. Such errors would cause planimetric displacement of $\Delta z \tan \alpha$

The departure of the film flatness and the efficiency of the electrostatic tightening of the film can also produce planimetric displacements. Errors due to film deformation can also arise from processing of the exposed film which will cause non-uniform scale changes if polyester-base film is not used.

4. Orthophotographic recording of building facades

The writer carried out recording of some building facades to verify the suitability of the orthophoto technique (MOHD. IBRAHIM, 1979). The orthophotos were produced by using the dynamic mode of scanning on the Zeiss Jena Topocart-Orthophot. The details and method of operation of the instrument are not described in this paper. It is hoped that the reader would refer to the instrument manual.

4.1 Types of surfaces chosen

Four different types of surfaces were chosen as follows:

1. Slight but sudden depth changes in the surface.
2. Great and sudden depth changes in the surface.
3. Great and continuous depth changes in the surface.
4. Slight and continuous depth changes in the surface.

In this context 'slight' includes surfaces with a depth change ranging up to about 15 cm. 'Great' includes surfaces which have depth changes greater than 15 cm. 'Sudden' is intended for surfaces where details on them drop at right angles to the surface. 'Continuous' applies to surfaces where details on them vary in depth in a gradual manner, that is, not at right angles.

4.2 Results of the scans

The orthophotos of two surfaces are shown in Figs. 12 and 13. They are orthophotos of a rockwall and bronze carvings respectively which fall under surface type 1 and 4. Fig. 14 is an orthophoto of the Bangunan Sultan Abdul Samad Kuala Lumpur that was recorded recently which incorporates all the four types of surfaces.

From the studies carried out on these surfaces, the writer made the following observations.

1) Buildings with continuous depth changes can be recorded well by the orthophoto technique, irrespective of the magnitude of depth changes.
2) Buildings with sudden but slight depth changes may be recorded.
3) Buildings with sudden and great depth changes are not suitable because of large scanning and system errors.
4) Buildings with protruding details cannot be recorded.
5) Surfaces which are planar or almost planar are ideal. Such surfaces can also be recorded by plane or conventional rectification.
6) The experience of the photogrammetric operator plays a vital part in obtaining orthophotos that are accurate and pictorially good.
7) The orthophoto technique is a particularly good technique in comparison with the stereoplotting technique if the surfaces contain plenty of intricate and artistic details. Stereoplotting of these details will not only be time-consuming but also it is not possible to plot all the details since selection of details to be plotted has to be exercised. Accurate measurement and plotting of such details by the conventional methods are almost impossible.
8) Ideally, the orthoprojection system used should have the Y — drive that is almost stoppable during the scanning procedure in order to follow difficult parts of the object with the floating mark. This would greatly reduce scanning errors.
9) To reduce system errors, a shorter slit width should be used which would obviously prolong the scanning time. This would produce an accurate recording if the scanning errors are minimised. On the other hand, a shorter slit width with large scanning errors can produce a pictorially bad orthophoto. If scanning errors are large but the slit width is larger, a pictorially better orthophoto can be obtained.

5. Conclusions

Orthophotography can be used in recording buildings especially where the surfaces change depth in a continuous manner, that is, there is no sudden change in the relief of the building. This technique is most ideal for surfaces with plenty of intricate and artistic details. It is not useful for buildings with great and sudden depth changes with many protruding parts. In these instances, stereoplotting is a suitable technique. In comparison with stereoplotting, orthophotography is a faster and equally accurate technique for certain surfaces. Therefore, parts of a building which are not suitable for orthophotography can be recorded by stereoplotting and the products of both techniques can be combined to produce an orthophoto-line-map of the building. Stereoplotting and orthophotography can therefore complement and supplement each other to provide a powerful technique for recording of buildings.

Acknowledgements

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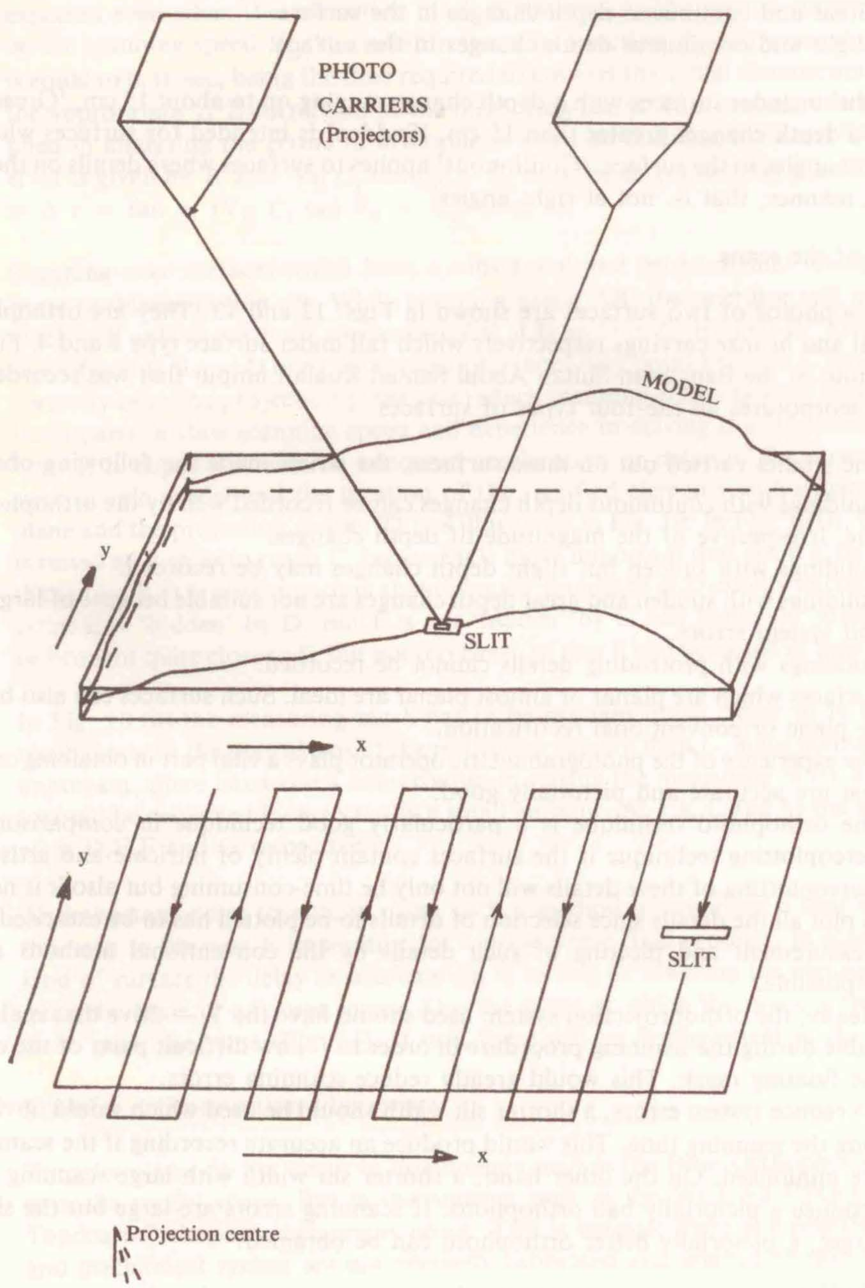


FIG. 1 STRIP-BY-STRIP SCANNING OF THE MODEL AREA

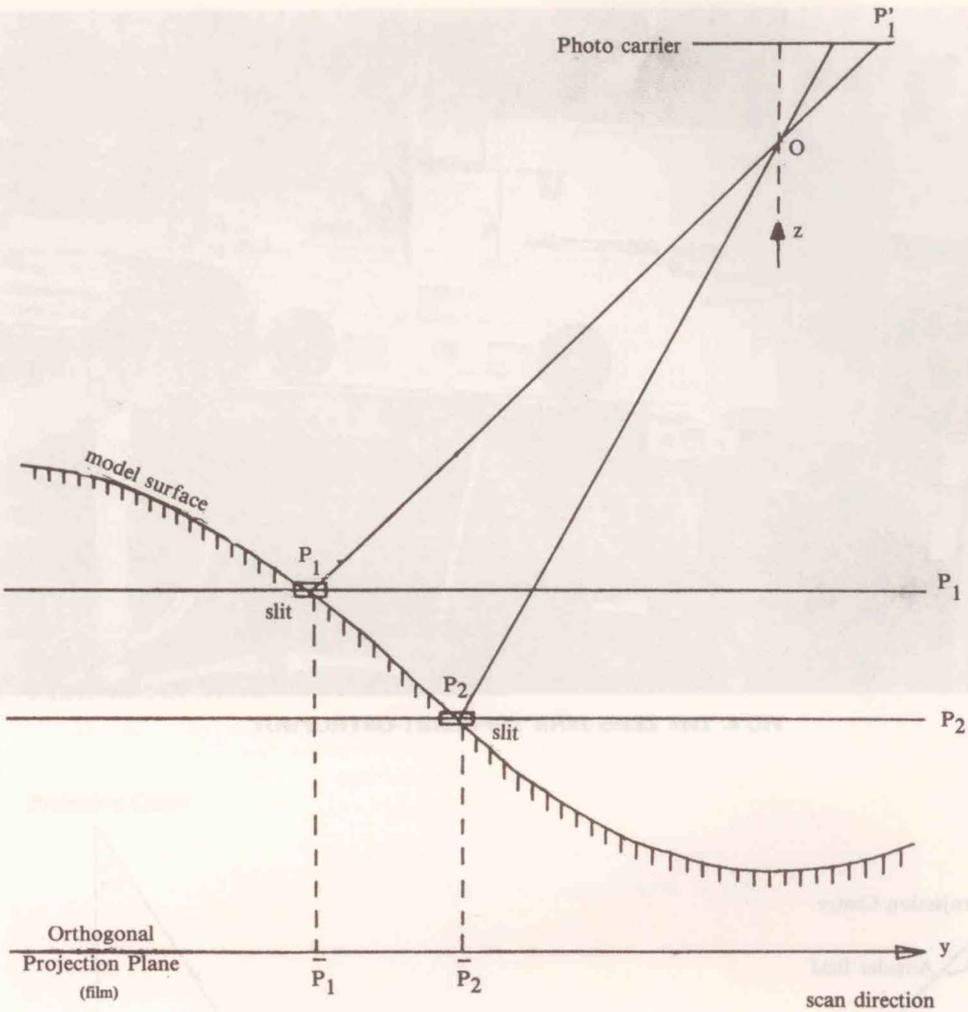


FIG. 2 DIFFERENTIAL RECTIFICATION

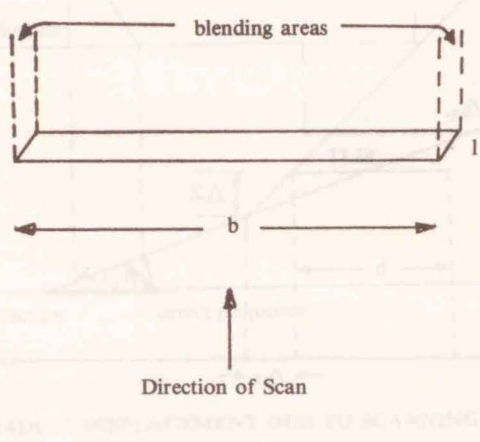


FIG. 3 SLIT SHAPE

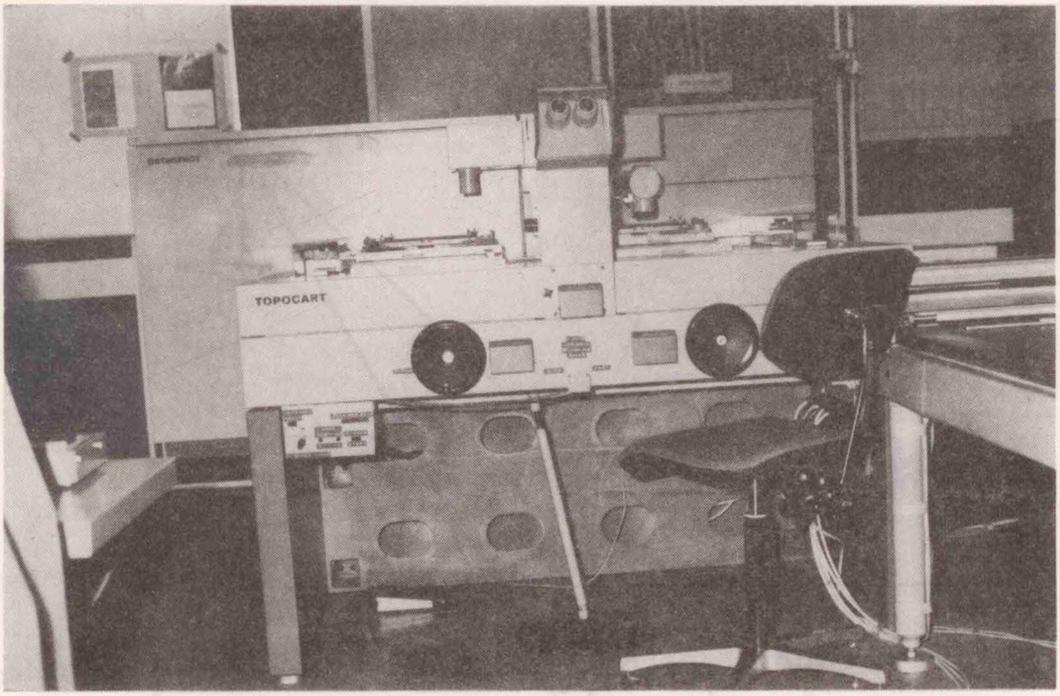


FIG 4. THE ZEISS JENA TOPOCART-ORTHOPHOT

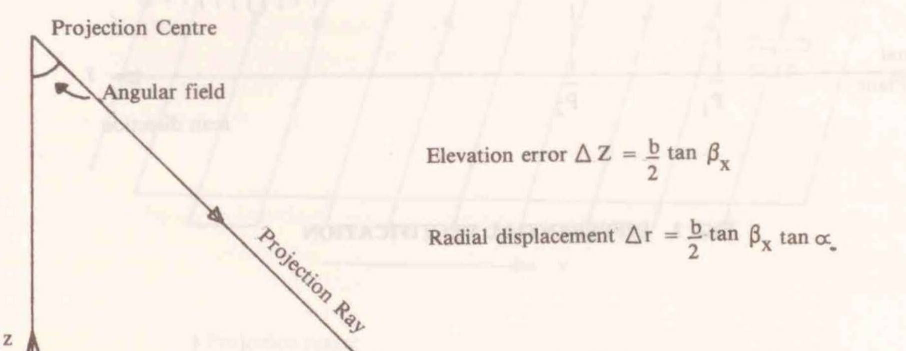


FIG. 5 SYSTEM ERROR DUE TO SLOPE IN THE MODEL SURFACE ACROSS SLIT WIDTH

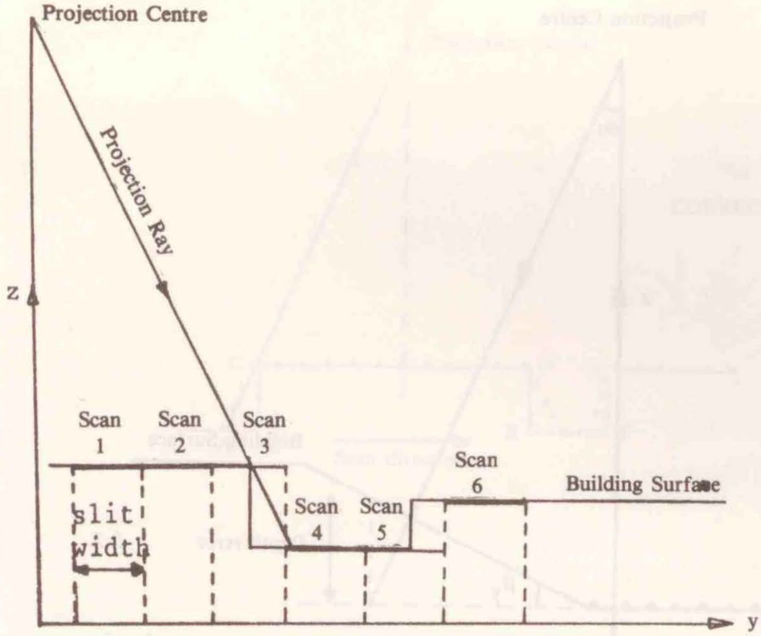


FIG. 6 PARTS OF THE BUILDING SURFACE AFFECTED AND NOT AFFECTED BY SYSTEM ERRORS

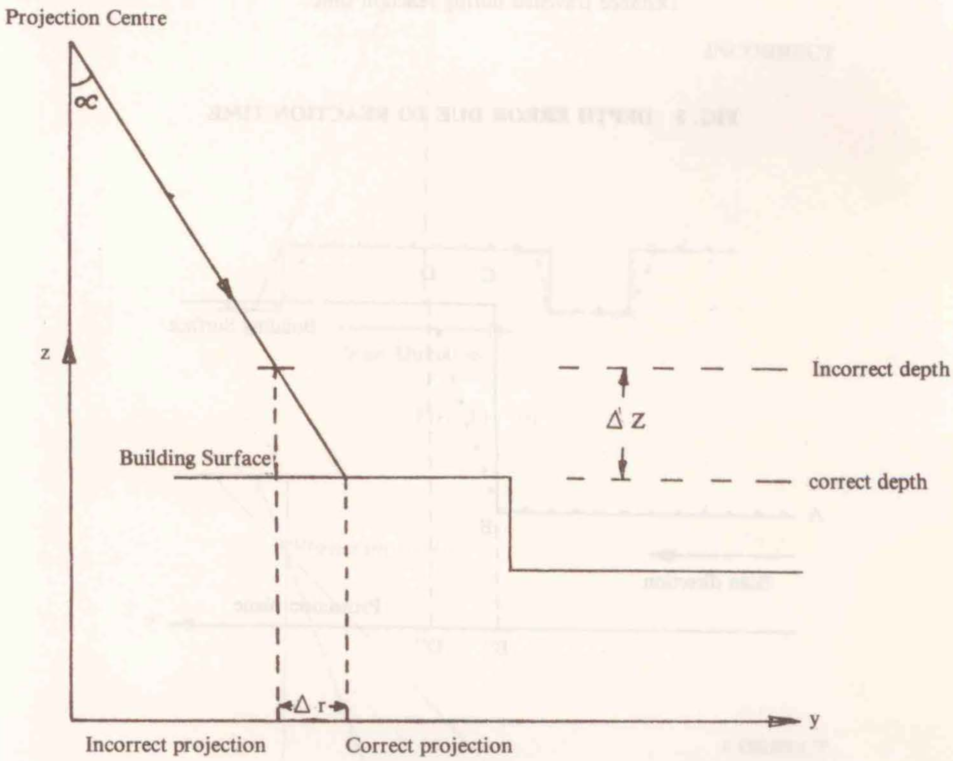


FIG. 7 RADIAL DISPLACEMENT DUE TO SCANNING ERROR

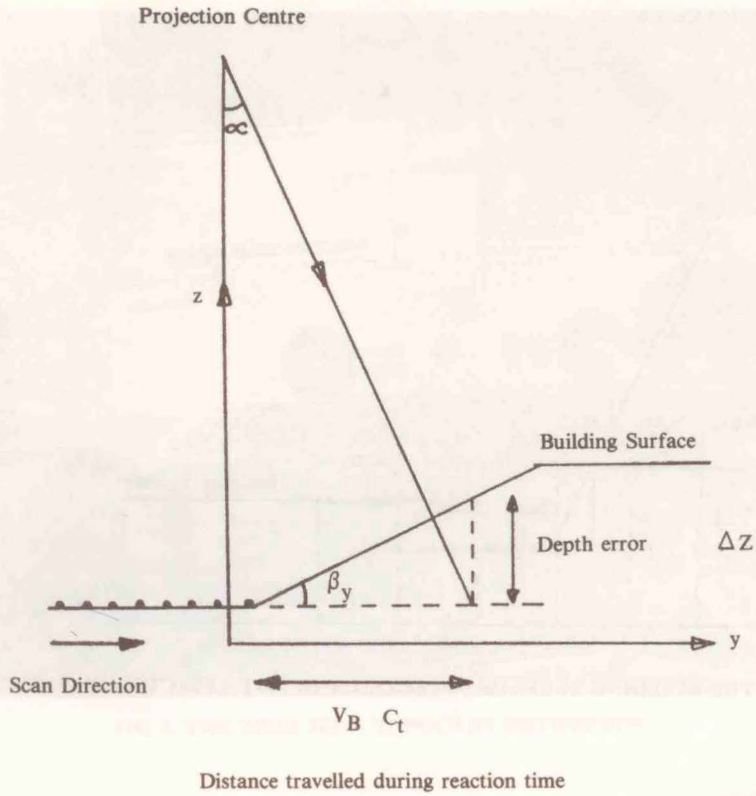


FIG. 8 DEPTH ERROR DUE TO REACTION TIME

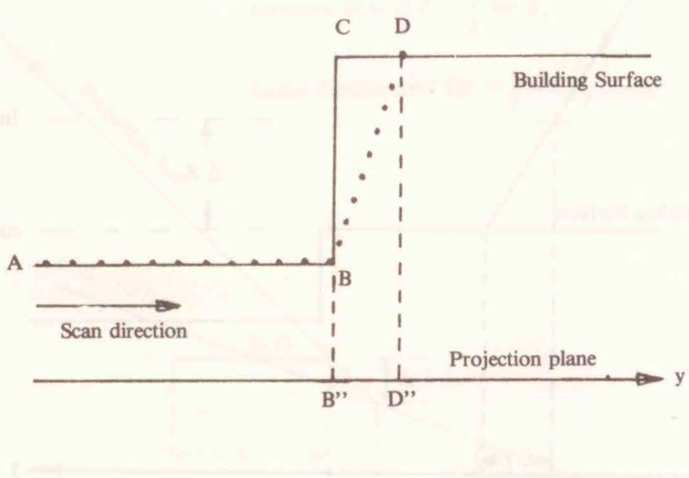


FIG. 9 SCANNING ERROR DUE TO SUDDEN DEPTH CHANGE

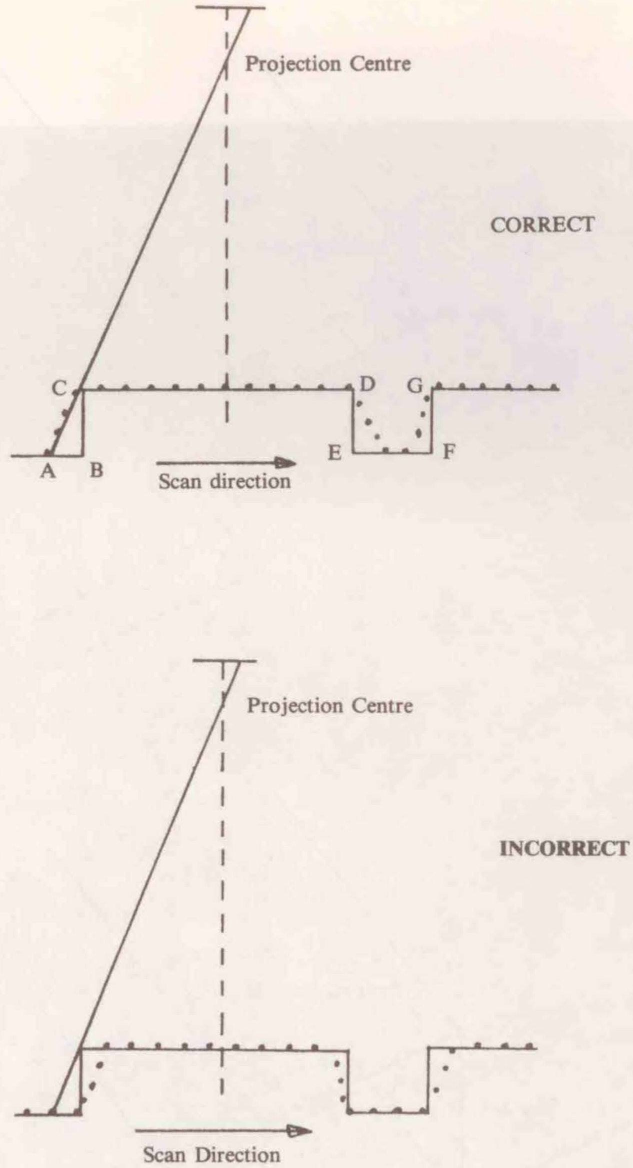


FIG. 10 (i)

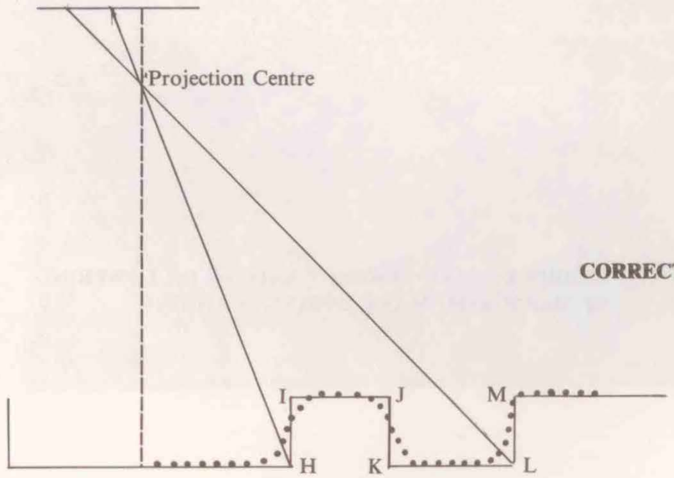
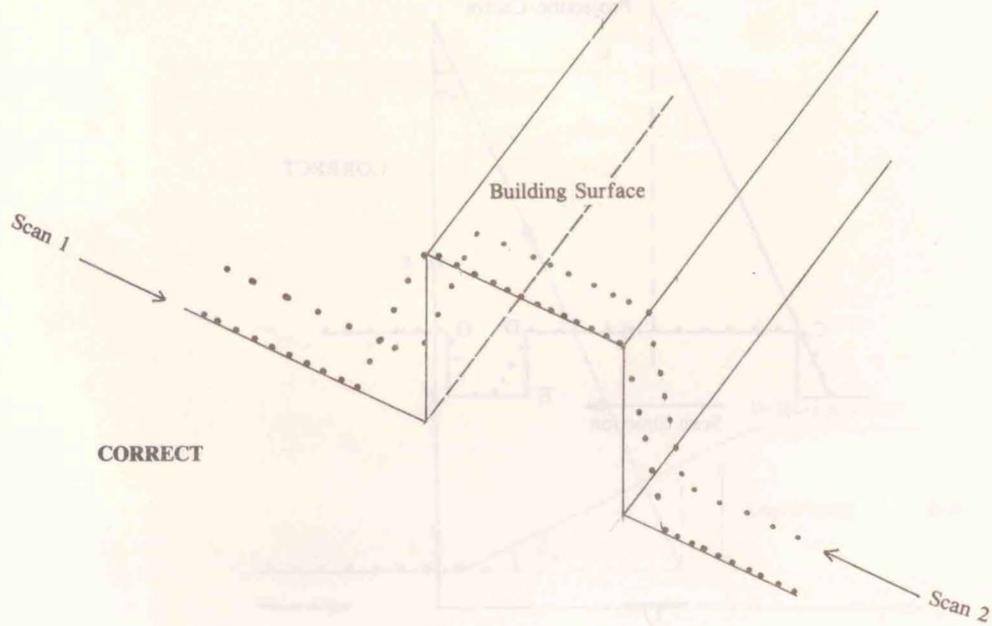


FIG. 10 (ii)

FIG. 10 THE WAY OF DRIVING THE MEASURING MARK DURING SCANNING



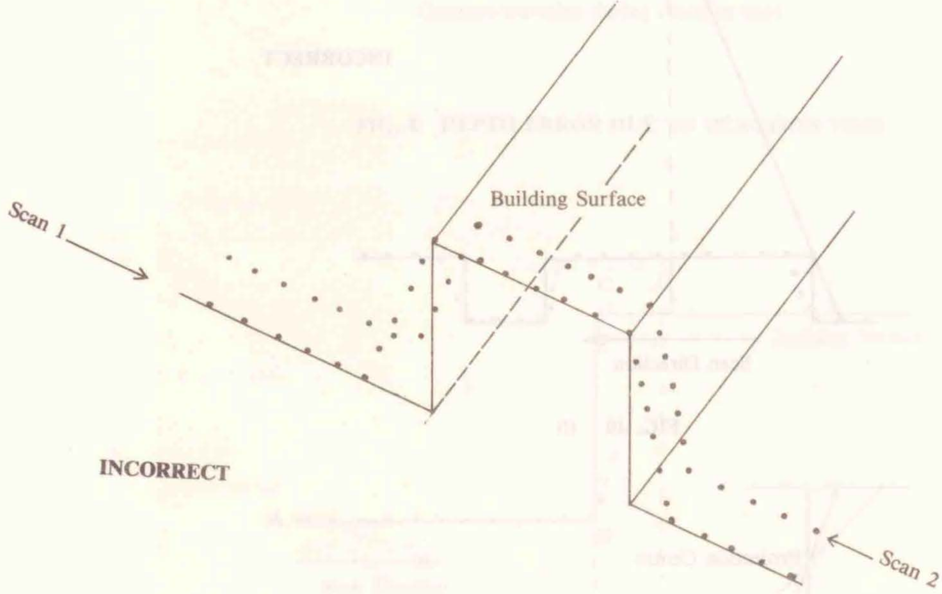


FIG. 11 CORRECT AND INCORRECT RAISING OR LOWERING OF MEASURING MARK DURING SCANNING

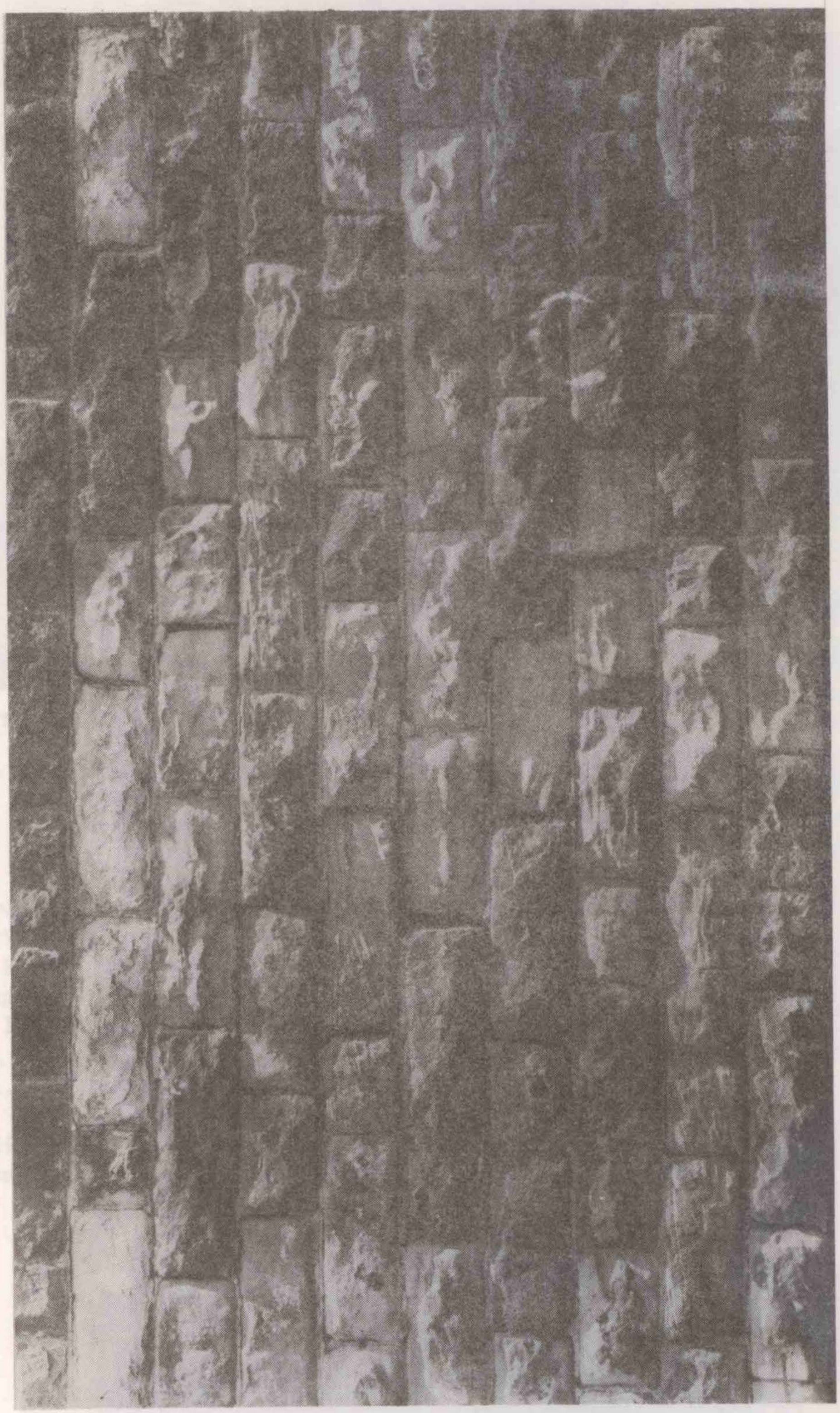


FIG. 12 ORTHOPHOTO OF ROCKWALL
SCALE 1:25

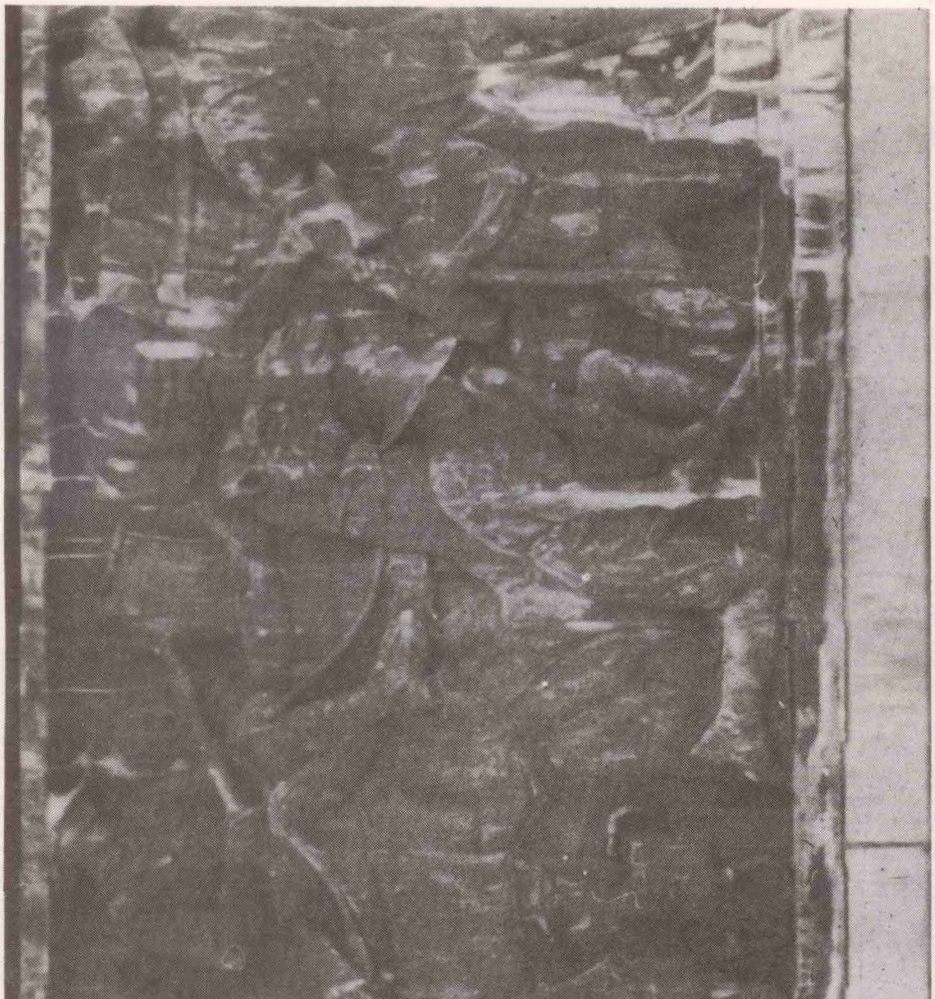


FIG. 13 ORTHOPHOTO OF BRONZE CARVINGS
SCALE 1:12

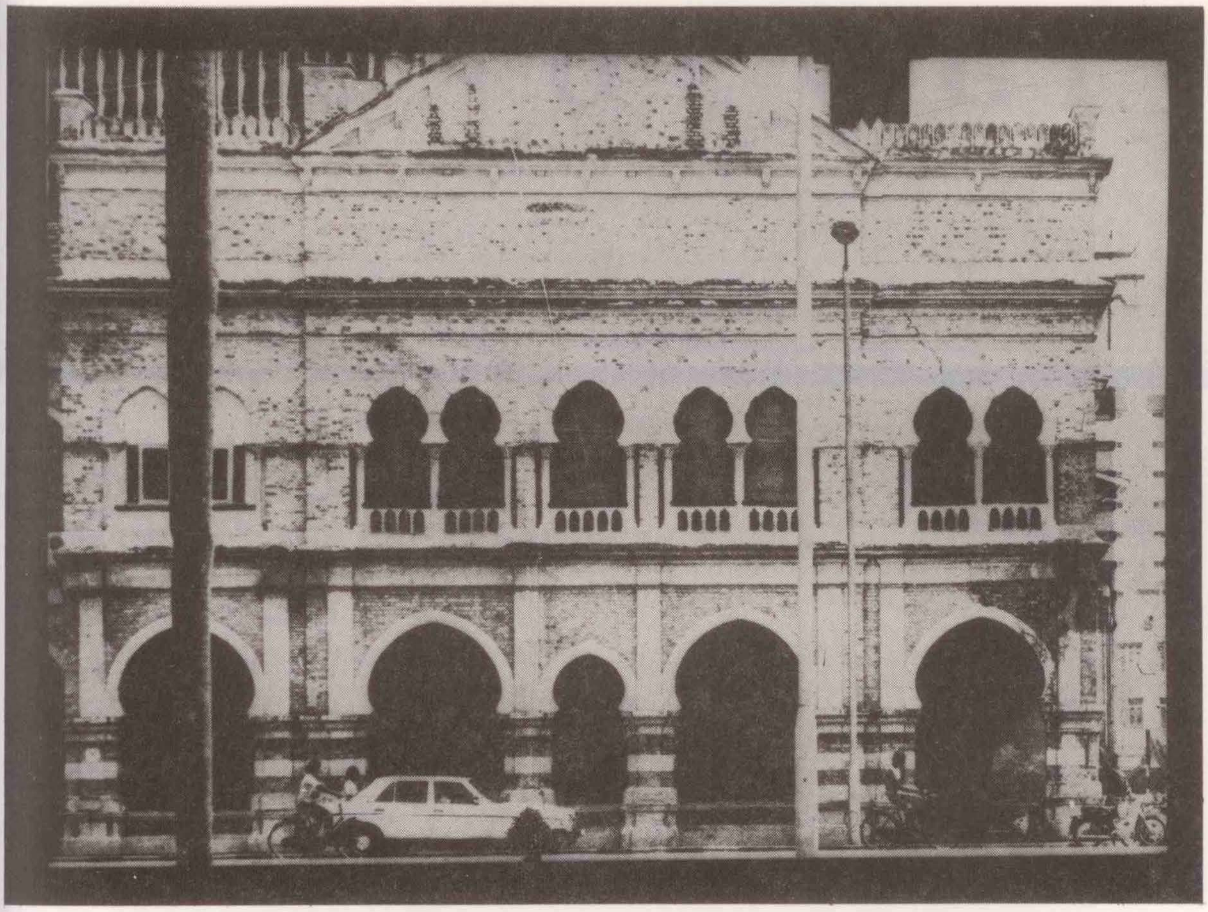


FIG. 14 ORTHOPHOTO OF BANGUNAN SULTAN ABDUL SAMAD KUALA LUMPUR
SCALE 1:150

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