USE OF X-RAY PHOTOGRAMMETRY IN ARCHAEOLOGY

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U S S R

Commission V

ABSTRACT: The present report shows the possibilities of the use of photogrammetry in investigation of archaeological objects. A testometric method of stereoroentgenogrammetric survey is considered, the design of the measuring test-object and survey methods are described, the possibilities of stereoroentgenogrammetric method are exemplified.

The practice of the use of stereoroentgenogrammetric survey in archaeology shows that this method permits to identify the found object, to define its form, dimensions and inner structure. The stereoscopic analysis of roentgenograms in cope with the measurement results permits to determine the distruction degree of the object and to choose the most efficient methods of cleaning and conservation of the object. Besides, the stereoroentgenogrammetric method permits to determine the manufacturing technology of ancient wares.

Archaeological objects of art constitute, among museum exhibits, a special group remarkable for its historic and aesthetic significance, and for its specific origin. These objects of ceramics, metal, glass, wood, fabric, etc. have, as a rule, "lived" hundreds and thousands of years by the time of their restoration as passive participants in various historical events. They sustained, under the effect of water, soil salts and carbon dioxide, a chemical and physical degradation which caused the cracking of objects of glass, ceramics and wood, the appearance of corrosion products on objects of metal, etc.

Thus the restorer and investigator of archaeological objects is confronted with a number of challenges. First of all, it is necessary to determine the extent of the preservation of as yet uncleaned object. Since the surface of archaeological objects is normally shielded, fully or partially, from the investigator's eye, and the object itself is brittle, the determination of its preservation, before its restoration and conservation begins, is a major physical problem. In addition to that, it is necessary to know the technology of its manufacture for the correct determination of its age and origin.

Most promising in the solution of these problems is the application of a stereoroentgenogrammetric technique, which has substantial advantages as compared with traditional roentgenography. Firstly this technique makes it possible to make use of high identification properties of stereoscopic vision when interpreting a photo of the internal structure of the object under investigation. Secondly, it enables one to construct, with a sufficiently high degree of precision, a geometrical model of the object (in a numerical or graphical form) [4] .

It is possible to use the roentgenodiagnostical apparatus "ARMAN", manufactured by Soviet industry (about 40 kg in mass) in order to carry out stereoroentgenography in the field. It is advisable to obtain a stereopair in normal photography by shifting the object under investigation to the distance of the photographing basis. In doing so, one can make use of a simple attachment with an investigation table mounted on a horizontal carriage. The table is made of an X-ray transmittant material, for instance, laminated insulation, with horizontal guides for an X-ray filmholder fixed on the attachment base under it. It is extremely difficult to determine with the required precision under field conditions the position of the true focus of the X-ray tube relative to the attached filmholder frame, therefore, the elements of the internal orientation of X-ray pictures of archaeological objects are, as a rule, unknown.

In this connection we employed a test metric technique of stereoroentgenogrammetric surveying. It is based on the use of a special measuring test object which is usually X-rayed simultaneously with the object under investigation. The internal structure of the object is measured by the stereopair of pictures on a stereocomparator using the image of the scales of the test-object. The technique is remarkable not only for its high precision, but also for its simplicity, as it makes unnecessary the determination of the orientation elements of photos, as well as the application of photogrammetrical conversion formulas [4] .

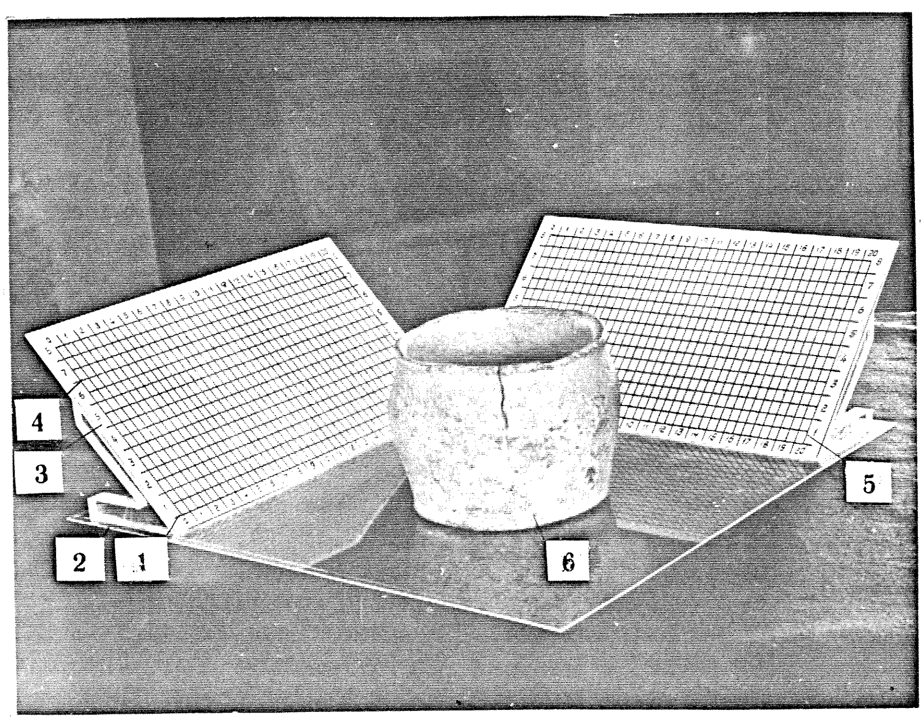

Fig.1.

The shape of the test-object is determined by the investigation objective. It is convenient to determine the space coordinates of points of the internal structure of the object with the aid of the test-object shown in Fig.1 [2] . The test-object has two identical scales 1 and 5 with X-ray contrasting lines 4 drawn on a hard X-ray transmittant plate 3. The scales are made by a photolithographic technique and re-inforced with a layer of tin. Each scale is fixed under an angle of 45° on plane-parallel base 2 made of plexiglass. The bases of the scales form an angle of 90° between each other. The X- and Y-axes of the test-object are parallel to the bases of respective scales 5 and 1, and the Z-axis is perpendicular to them (lines X,Y and Z are drawn with the specified quantification).

The measuring test-object is placed on the attachment table and oriented so that the X-axis should be parallel to the direction of movement of the horizontal carriage. The object under investigation, for instance, clay pot 6, is placed in the zone between scales 1 and 5 (see Fig.1). The X-ray tube is fixed on a stand over the table. After the first photograph has been taken, the horizontal carriage, on which the table is mounted, is shifted to the distance of the photographing basis and fixed with a lock screw. The second photograph of the stereopair is taken after re-loading of the filmholder. The X-ray tube remains immobile in the course of stereoroentgenography.

It was already noted that the stereopairs of X-ray pictures are processed on the stereocomparator; reduced slides can be used for this purpose. The pictures are oriented so that the X- and Y-axes of the test-object should be parallel to the x- and y-axes of the stereocomparator. After a stereo model has been obtained, the leading mark is sighted on the sought-for point of the visible structure. Then, without changing the setting of the parallactic screw, the leading mark is shifted parallel to the y-axis of the instrument until it matches with the images of the nearest reading lines X, Z, and readings are taken by the X- and Y-coordinates scales of the test-object. If the leading mark is positioned between the two lines, the reading is taken by the interpolation technique, knowing the value of the point on the metering scales. The Y-coordinate is similarly obtained from the ordinate scale of the test-object.

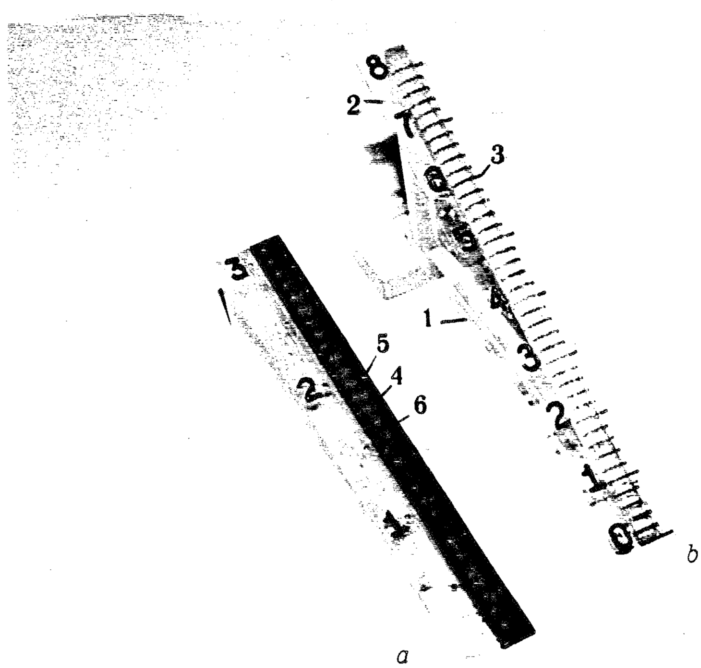

Fig.2.

It is advisable to use an inclined ruler with an X-ray contrasting scale as a test-object whenever the conditions of surveying require determining the position depth of the structural elements of the object under investigation[1] . Two such rulers are shown in Fig.2.

Lines 3 of the ruler (Fig.2, b) can be made of a fine steel wire for the investigation of objects made of fabric, wood and ceramics, when roentgenography is to be carried out under soft and medium conditions. The lines are fixed on plane-parallel plate 1, mounted slopingly on support 2. The plane-parallel plate and support are made of plexiglass. The initial line of the ruler is aligned with the base of the support and the excess of each following line, relative to the preceding one constitutes:

$$\Delta h = \Delta S \sin\alpha,$$

where ΔS is the distance between the lines, and α , the inclination angle of the ruler scale.

The scale of the inclined ruler (fig.2, a) is made for a thin lead band 6 whose lines are formed by through holes 5 with a small diameter for the investigation of objects of metal, when hard conditions of roentgenography are to be employed. An additional row of holes 4 makes it possible to ascertain the linear dimensions of the structures under investigation by means of an X-ray stereopair.

The inclined ruler is placed on the investigation table next to the object under investigation so that its scale should be in the plane perpendicular to the photographing basis. Stereoroentgenography is carried out under normal conditions of surveying. The stereopair obtained is fixed in the pictureholder of the stereocomparator and oriented according to the coordinate marks until a stereomodel is formed. After that the leading mark is sighted on sought-for point A of the internal structure of the object under investigation. Then, without changing the parallactic setting of the instrument, the mark is shifted until it matches with line A' of the photo of the inclined ruler scale. The excess of point A, relative to the plane of the investigation table, will be equal to the resulting reading $h_{A'}$. In the case of the leading mark taking position between neighbouring lines the reading is to be taken by the interpolation technique. The position depth of point A relative to the external orientation X-ray contrasting mark M, fixed on the surface of the object under investigation, is equal to

$$h_{M'} - h_{A'}$$

($h_{M'}$ is the reading off the ruler).

The testometric technique of stereoroentgenographic surveying was employed by us to investigate some archaeological objects made of ceramics, metal and fabric.

A sufficiently complex problem in archaeology appears to be the determination of conditions and methods of the moulding of pottery articles which are found in mass and are frequently alone that can be dated. The ascertainment of the manufacturing technique of ceramic articles (by moulding them on a potter's wheel, or by modelling) is of major importance in the historical interpretation of archaeological information. An X-ray picture is the only possible means of establishing the real conditions of the manufacture of ceramic articles on the basis of the study of the rotation speed of plastic clay mass during moulding. Indicators of the degree of the dynamics of the clay mass are the character of its compression and distribution, the orientation of pores and material making the clay mass lean.The clay mass of articles made by modelling is characterized by higher statics; a slight shift of the mass can sometimes be observed, one can rarely see variously directed orientation of its areas and admixtures making it lean.

The real condition of the clay mass can be easily observed in an X-ray picture. This fact is used in the archaeological practice to ascertain the time of the introduction of a potter's wheel [3] . A single X-ray photo, however, does not make it possible to obtain a complete picture of the spatial distribution of pores and admixtures making the clay mass lean. This causes difficulty in the differential interpretation of pores and admixtures making the clay mass lean (indicators of the dynamics of the clay mass) and in the determination of a difference between them and cavities, scratches, various kinds of pollution and other defects in the surface of a ceramic article. Since these defects may have a systematic orientation, an error in the interpretation of an X-ray picture of ceramics can result in the wrong interpretation of the direction in which the clay mass was moulded.

A stereoscopic model of a ceramic article, restored by X-ray pictures, makes it easy to isolate pores and admixtures making the clay mass lean. It is also easy to identify external defects (cavities, scratches, foreign particles, etc.) which, as a rule, mottle the outer and inner surface of an ancient object.

Stereoroentgenogrammetric surveying makes possible the determination of the coordinates and orientation of pores and admixtures making the clay mass lean, as aresult of which experts can ascertain the direction in which a clay article was moulded, the rotation speed of a potter's wheel, etc.

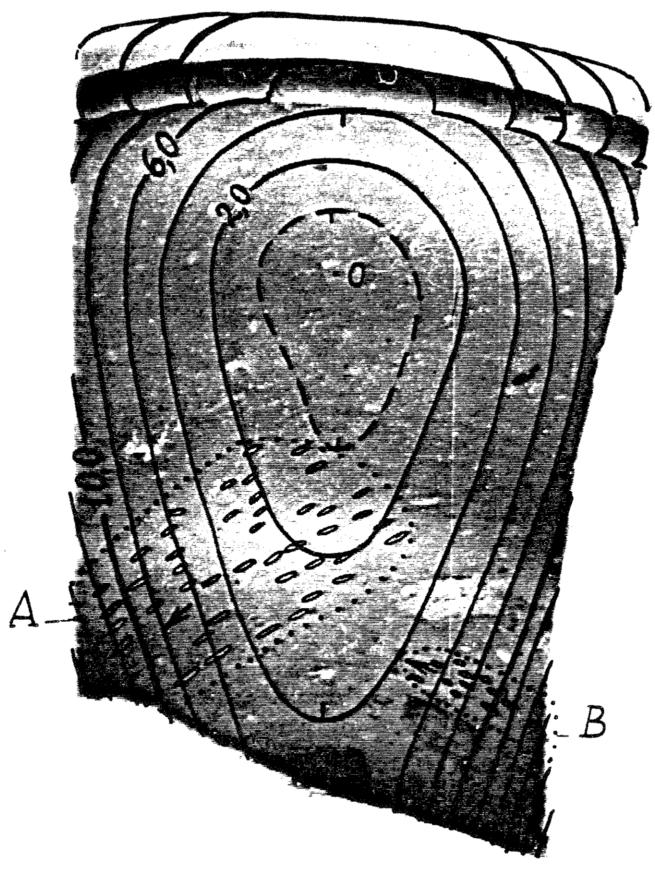

Fig.3.

We shall cite as an example the results of the stereoroentgenogrammetric surveying of a fragment of a vase-like vessel from the Shor-Depe settlement (Southern Turkmenistan, late 3d - early 2nd millenium B.C.). Fig.3 shows a contact print of the right-hand photo of the X-ray stereopair of this object, where horizontal lines, drawn after every 2 mm portray the outer surface of the ceramic article.

In zone A, cut off with dot lines, one can easily observe a multidude of small bright formations of an elongated shape, oriented clockwise. It was established, as a result of the photogrammetric processing of the stereopair, that these formations are inside the ceramics at a distance of 1.8-2.3 mm from the outer surface of the vessel. The wall of the vessel in zone A is equal to 4.8-5.1 mm. The information obtained demonstrates the fact that the bright formations are pores elongated under the effect of the motion of the clay mass when it was being moulded on a potter's wheel. Experts became also interested in zone B where the directed orientation of particles is also noticeable. A stereoroentgenogrammetric analysis showed that these are the images of foreign particles present on the outer surface of the vessel wall, and having no relation to the shifting of the clay mass during the moulding. This particular example is a graphic demonstration of the advantages of the stereoroentgenogrammetric technique in the investigation of ceramic articles.

Fig.4.

There are cases in the archaeological practice when the object found is completely covered with corrosion, or a tightly baked coat of various soil products, which makes it impossible to characterize the finding. It is not always possible to clean the outer layer because of the danger of destroying the poorly preserved object. It is precisely in this case that the stereoroentgenogrammetric technique can become the only method making possible the identification of the object and the determination of its shape, dimensions, structure and the extent of degradation. A similar situation arose when investigating an object found during the excavation of burial mounds in the Ukraine. It resembled in appearance dried-up wood bark with mossy edges. A fine golden wire (Fig.4) was perceptive in some areas of its surface. A stereoscopic analysis of X-ray pictures of this object demonstrated that a decorative pattern, made with a golden thread (Fig.5, a stereopair), remained under the outer layer of soil products. An investigation of the pattern showed that it was made with a twisted thread, composed of several 0.15 mm thick threads. The remaining fragments of the pattern are in the shape of a double spiral with an outer diameter of 3.2 to 5.4 mm. There are areas with a parallel "run" of the threads forward and reverse, their length being 9.2-9.4 mm. Alongside the partially remaining pattern there can be observed a scattering of separate golden particles of round shape (0.2-0.7 mm in diameter) resulting from the destruction of the thread.

a *b*

Fig.5.

Thus the stereoroentgenogrammetric technique made it possible to establish that the finding was a fragment of an ancient textile, embroidered with a fine golden thread. The structure of the thread was determined, and also information was obtained as to how to restore the technology of embroidery.

The experience of the employment of the test metric method of stereoroentgenogrammetric surveying for these purposes showed that it was able in most cases to solve major problems of archaeology: make the interpretation of the internal structure of an object, ascertain the extent of its preservation, as well as determine the manufacturing technology of the object under investigation.

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