CHAPTER V

PROCEDURES X-RAY PHOTOGRAMMETRY

5.1 COMPUTATION POSITIONS X-RAY FOCI AND MARKING BALLS

To calculate the positions of the two X-ray foci, we used the focus locating apparatus (FLA) (see Figure 5-1). This apparatus consisted of a rectangular base with three balls fixed in position above it (P_1, P_2 and P_3; see coordinates Table 6-1, page 46).
The spatial positions of these balls in relation to an angle point of the base have been determined on an optical measuring bank at the Kamerlingh Onnes Laboratory, National University of Leyden. The FLA is placed in the cage in such a manner that the point of intersection 0 of the ribs and the angle point of the FLA are as close as possible (theoretically coinciding), Subsequently, a lateral X-ray of the balls is made on the vertical film (focus roentgen source B_1) followed by an (oblique dorsoplantar) X-ray on the horizontal film (focus roentgen source B_2).

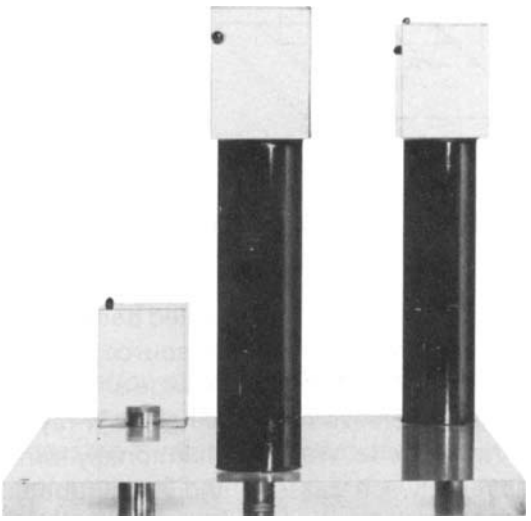

Figure 5-1. Focus locating apparatus (FLA).

The situation is schematically shown in Figure 5-2. Source B_1 projects balls P_{2s} and P_{3s} on the vertical roentgen film as P_{2v} and P_{3v}, respectively. After photogrammetric determination of the positions of P_{2v} and P_{3v} in the X-ray (see below, par 5.4), the positions of P_{2v} and P_{3v} in relation to O can be computed (see Chapter 3.6.2). Then, a line passing through P_{2v} and P_2 is computed; this line ought to pass through focus B_1. The line through P_3 and P_{3v} is also calculated and this, also, ought to pass through focus B_1.
Theoretically, these two lines ought to intersect in B_1. Owing to systematic errors and measuring errors, they do not intersect but cross. For this reason we also calculate the shortest perpendicular distance between these two crossing straight lines. As the coordinates of focus B_1, we then regard the coordinates of the point situated halfway this shortest distance. Subsequently, an identical procedure is applied using points P_{1s}, P_{2s}, P_{1h} and P_{2h} for the location of focus B_2.

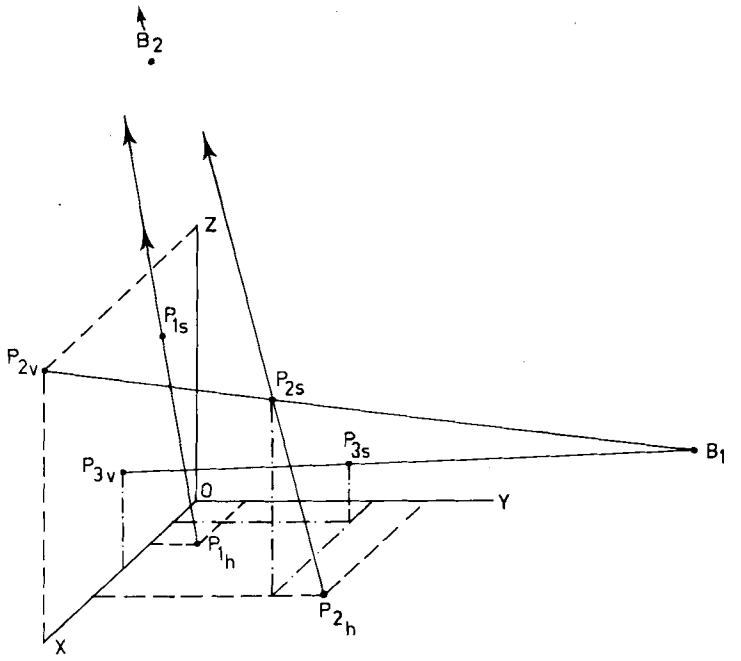

Figure 5-2. Scheme of computation of coördinates of roentgen sources B_1 and B_2, respectively.

When the shortest possible distance is calculated between two lines that cross at a narrow angle, the error in the location of the source will be relatively important; the distance between two lines that cross at a wide angle gives a relatively minor error. The latter might be achieved by placing the X-ray tube at a fairly short distance from the X-ray cassette. We have intentionally refrained from doing so, since a short distance between cassette and X-ray tube causes considerable distortion of the X-ray image of the tarsus so that the outlines of the tarsal bones could no longer be interpreted adequately. Accuracy of source locating is

achieved by application of a socalled iterative procedure; this procedure is described in Appendix (A).

Once the source coordinates have been computed as described above, the spatial positions of the tarsal marking balls are calculated in an analogous manner. This is already represented schematically in Figure 3-1.

5.2 MARKING OF THE BONES

The positions of the pins (and the marking balls) in the bones had to meet a number of conditions for the measuring as well as the computation procedure:

a. the pins had to be enclosed completely by the bone, not only to prevent them from interfering with the articular movements, but also with a view to the computing method applied.
   The bundles of radiation from B_1 and B_2, respectively, had to make an angle of at least 15° with the direction of the pins.
b. The projections of the marking balls should not overlap in any of the positions exposed.
c. The marking balls had to show up with good contrast in the X-ray in all positions; they should not be imaged in areas where relatively much bone mass was projected because in that case the position would not be computable with accuracy.
d. The site of the insertion had to be relatively easily accessible so that insertion would cause only minimal damage to ligaments.

The above may explain why initially we found the correct pin positions in a test preparation by trial and error. In this manner, a protocol for implantation of the pins in the correct direction and position was elaborated.

5.3 EXPERIMENTS

The foot-lower leg preparation is placed in the cage with the back of the calcaneus at approx 1 cm distance from the Y-axis and the lateral surface of the calcaneus at approx 3 cm distance from the X-axis. Subsequently, source B_1 is centred on the bifurcate ligament. This rough positioning is required to keep the projections of the tarsus and of the reference strips within the indicated area of the X-ray film.

In order that a useful projection of the tarsus will also be obtained with source B_2 in the dorsoplantar direction, the bundle is aimed at an angle of 15° from the vertical. To this purpose, the X-ray tube in relation to the coordinate centre O is placed at a distance of approx 30 cm in the X-direction and at approx 120 cm distance in the Z-direction, and centred on the centre of the head of the talus. This, also, is a rough positioning to keep the image of the tarsal bones and

reference strips within the indicated frame. After this rough positioning of the X-ray tubes, the preparation is taken from the cage for the time being, after which the exact focus-locating procedure is completed. Following the focus-locating procedure that preceded every experiment (see Chapter 5.1 and the Appendix), the foot-lower leg preparation is returned to the cage with the tibia in a neutral position in relation to ab- or adduction and plantar or dorsal flexion. Subsequently, the central axis of rotation of the cage with the locking ring for the tibia is moved in plane XY until it is over the tibial plateau, after which the tibial locking ring can be let down over the tibial plateau. Subsequently, the axial load is applied to the central axis of rotation by hanging the two weights from it. Thereupon, the eight clamping screws fastened tightly into the proximal tibia. Then, one of the vertical forefoot supports, depending on whether a left, or right-sided specimen is involved, is placed against the lateral edge of the foot; this support should prevent an abduction movement of the forefoot during exorotation of the tibia.
With the aid of the electric propulsion mechanism, the tibial exorotation movement is carried out several times. If it is found that the calcaneus slips away over the platform, for instance because the tibia is still in an adduction position after all, positioning is repeated. That starting position is chosen in which the calcaneus no longer slips away over the platform. This position is selected for position zero. Then, in this zero position, a dorsoplantar and a lateral X-ray are made of the tarsus. Thereupon, the central axis of rotation of the cage is rotated manually through 5°; the pall can then be introduced into the 5° ratchet mechanism, after which this position is secured by tightening the clamping screw of the vertical axis. X-rays in the dorsoplantar and the lateral projection are then made of this position, and this is repeated for each subsequent 5° exorotation step. With most preparations, a maximum of 7 steps of 5° proved possible, with a few, only 6 steps were possible. The limit of the number of steps was indicated by tilting of the foot with the calcaneus slipping off the platform.

5.4 MEASURING X-RAY PHOTOGRAPHS

In view of the fact that our method required measuring with a high degree of accuracy, a comparator (type Wild A 10) was used to measure the coordinates of measuring points in the X-rays. It was kindly placed at our disposal by the Technical University of Delft dept. of Geodesy. Of the comparator we only used the XY-coordinate system in the horizontal plane. Measuring was done by focusing an ocular with centering point on a measuring point. This ocular, adjusted to give a magnification factor of 3, is situated perpendicularly above the XY-plane. The X- and Y-coordinates of the measuring points in relation to the axis system of the comparator are then measured in a fixed sequence.

The coordinates of the centres of the marking balls are computed by measuring the four points of contact in the largest transverse section in the X- and Y-

directions of the image of the balls. The mean values of the X- and Y-coordinates determined in this way are regarded as coordinates for the 'centres' for the subsequent computation procedure.

The X-ray films can be placed in the comparator in any position provided they are lying flat, because the position of the projected coordinate system of the X-ray film in relation to the coordinate system of the comparator is also calculated.