of climate, and characteristic slopes occur throughout climatic zones (or broad climatic regions). The observation of these slopes has been more definite than an accounting for their occurrence, especially in the tropical areas similar to those considered in the present study.

The study is of a subtropical region with 88 inches of annual rainfall, distributed without pronounced seasonal variations. The writer considers these conditions as analogous to tropical humid regions. Among illustrated topographic features are those which occur in tropical semiarid regions.

A second area consists of a tropical semiarid (seasonal rainfall) region. Many of the observed topographic details are common between the two areas investigated, but among the semiarid features, soil flowage at "depths below that anchored by roots" (a tropical humit phenonenon) is shown.

The writer suggests, as a primary hypothesis, that all tropical slopes (except arid and karst regions and those of sufficient elevation to remove them from tropical considerations) may result from the same erosion agency as is mentioned in the title.

*Measurement of Contrast in the Aerial Image**

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ABSTRACT: *The quality of a lens is evaluated by examining the image it produces and comparing it with the object or target of which the image is made. An instrument has been developed which scans the aerial image directly with a slit and photomultiplier tube. The resultant variations in luminosity in the image are recorded on a moving chart paper. This process substitutes a linear receiver or phototube for a non-linear receiver such as an emulsion. Results are shown in which contrast is plotted against image frequency for several f/values of a lens. A comparison is also made between image contrast and star images at several focal positions. A second comparison is made between measured contrast and best definition at several focal positions.*

ANALYZING the image of a lens as a means of judging its quality or capabilities might be compared to determining the response of an electronic amplifier. In each case, a known quantity is presented as input and the resultant output is analyzed and compared with the input. Both amplifier and lens are limited in response to the input signal. Beyond this limit in each case is only noise, either electrical from the amplifier, or light in the optical image.

In setting up a lens for test, an illuminated target is placed in front of the lens, within limits of distance and field angle, to produce an image.[1] This image exists only in space, to be seen and examined, it is usually registered by one of the following methods:

1. A diffuser is employed such as a ground glass which allows immediate examination of the image at the expense of considerable degradation of quality;
2. A photographic emulsion such as a film or plate is used in which a secondary chemical process is necessary to bring out the latent image for further examination;
3. The primary image is used as the object of a projection lens system such as a microscope objective. This approach, or the one permitting the image to fall directly on a slit, is referred to as the "aerial image."

To make the third method as objective as possible and to reduce the subjective or human element, a procedure for instantaneous read-out must be established to minimize the use of the eye. The phototube is an excellent tool and is used in this method since it responds to the amount of luminous energy falling on it. The response is the product of the area, the energy density, and the spectral response of the tube. This response varies as

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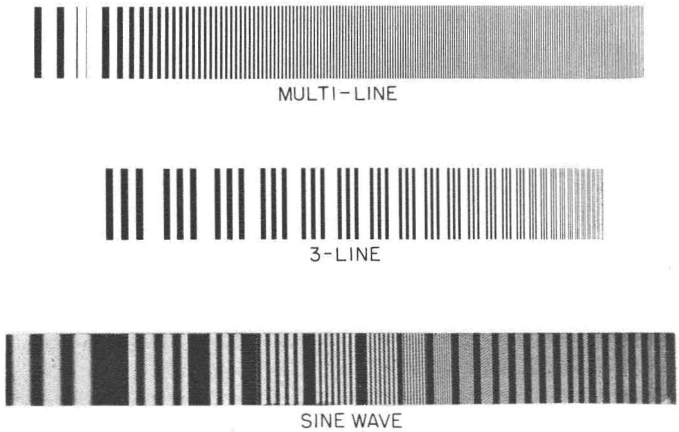

FIG. 1. Three types of resolution targets which have been used to determine image contrast.

the area of the light beam striking the tube is changed. The conventional way for controlling this variable is by use of a slit which renders constant the illuminated area, the source of illumination being constant. The tube is then required to read out only the variations of illuminance from one very small area of the image to another.

The entire image is scanned by movement of the image of the target relative to the phototube-slit combination. This movement, accomplished by lateral movement of the target, allows the receiving slit to be always in the same axial position of the lens under investigation.

The signal from the target must function as a known input to the system and the detail of the signal should have a geometric resemblance to the receiving slit shape. A target was therefore developed with detail in the form of parallel lines and spaces, commonly called the bar type of target.[2] The lines and spaces can be varied in width to produce coarse and fine patterns. The fine pattern in the target is in the range of high spatial frequency. The spacing from bar to bar generally varied between $\sqrt{2}$ and $\sqrt[6]{2}$.

A high progression rate target provides for a longer range of frequencies but gives less accuracy at locating a given frequency than a low progression rate target of the same overall length. The latter has a shorter range of frequencies but it provides more steps. In these two targets an opportunity also exists for variation in the arrangement of the line patterns, which are usually composed of groups of three lines with a constant line space width for each group.

Another type of target is one in which each line and space differs in width in a continuous manner from the adjacent lines and spaces. Target transparencies that are positive or negative in regard to line patterns and background can also be used. These transparencies may have clear lines with an opaque background or vice versa. In general the limits of resolution observed with positive and negative targets will not be the same. A target with a clear background will usually give a lower resolution limit due to the increased amount of flare light contributed by the background.

In choosing a target, other factors to be considered are the length of the line the target produces in the image plane, whether the line is longer or shorter than the receiving slit, and target contrast. Contrast is the difference in density between dark and light parts of the target detail. Three types of targets in general use are shown in Figure 1.

When the target is moved in a plane parallel to the image plane along a line at right-angles to the line pattern on the target, the image will correspondingly move in its plane. With the slit in the test instrument fixed, the target image passes over the slit. As the phototube and slit measures illuminance, a measure of the respective transmission of each line and space is made. If the transmissions of the lines and spaces are termed T_L and T_S respectively, the contrast is expressed as:

$$C = \frac{T_S - T_L}{T_S}.$$

If the results are measured in terms of density, the contrast is determined by the

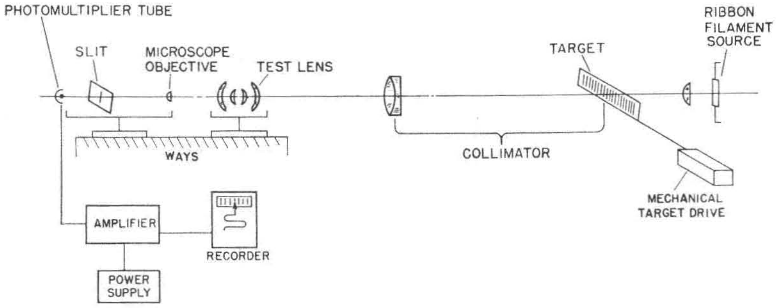

FIG. 2. A schematic layout showing arrangement of apparatus as used to determine image contrast.

difference of the line and space densities. Thus:

$$C = \Delta D = D_L - D_S.$$

In the newer types of rapid scanning electronic benches, which use a target whose transmittance fluctuates sinusoidally while scanning lines and spaces, a term called contrast transmission function or modulation is employed. This modulation is expressed as:

$$M = \frac{T_S - T_L}{T_S + T_L}.$$

Determinations are made of target modulation (M_t), and of the image produced by the lens under test (M_i). A simple ratio of the two yields a value called response:

$$R = \frac{M_i}{M_t}.$$

The equipment currently in use at the National Bureau of Standards generally satisfies the conditions required for analyzing an aerial image of a target. A schematic diagram of this equipment is shown in Figure 2. The source is a ribbon filament tungsten lamp focused by a condensing lens on the target located at the focus of a collimator. The lens under investigation is located on a nodal slide in the collimated beam. The nodal slide and pickup unit are mounted on separate saddles that ride on a length of ways which has been aligned with the optical axis established by the collimator.

Immediately behind the test lens is the pickup unit consisting of microscope, slit, and phototube. Associated equipment is used to amplify and record the output of the tube. As the receiving slit and source remain stationary on the axis of the system, and as only a small portion of the target is illuminated at one time, the entire target is scanned by one movement across the optical axis. A short length of ways guides this movement and a synchronous motor provides the power. The instrument is operated in such a manner that the image of the entire target is allowed to pass over the receiving slit.

Tangential and radial line patterns are produced from one target by rotating the lens in the nodal slide about two different axes: a vertical axis for tangential patterns, and a transverse horizontal axis for radial patterns.

Figure 3 shows two traces made by scanning the aerial image of the target. The trace forming the outer envelope—the one with the largest magnitudes of oscillations—was made at a focal position near best focus. The inner trace was made at a focal position 1.2 mm. inside of the first focal position. The lens under test was of about 150 mm. focal length.

The two traces have been started in phase at the low frequency end of the target. By following the inner trace it can be seen that resolution ends at the first null point where one half of a line is lost, and where apparent or spurious resolution starts. By using the outer trace as a control, it can be seen how in this area of spurious resolution, transmission is out of phase. A line is indicated where a space should be. The next null point indicates the loss of another one half of a line. This loss puts the lines and spaces back in phase, but a count shows one whole line and space missing.

The only measurable quantity in this type of investigation is the light flux. There are many parameters which can be given different values, resulting in a corresponding variation in light flux. Some of these parameters are associated with the lens, for example: location of focal-plane, off-axis location of receiving slit in the focal-plane, and f/value. Typical parameters associated with the target are: contrast, type (such as square wave or sine wave, and positive or negative), spatial frequency, and line orientation (radial or tangential). A source parameter is spectral range.

Figure 4 illustrates a plot in which contrast

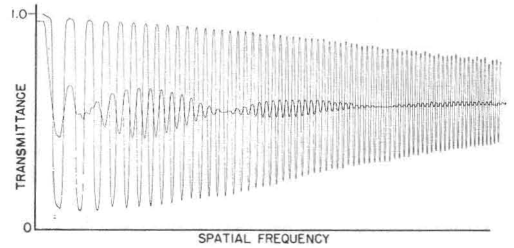

FIG. 3. Recorder trace showing the response in the aerial image at two focal positions, The outer trace was made near the best focus while inner trace was at a location 1.2 mm. nearer the lens.

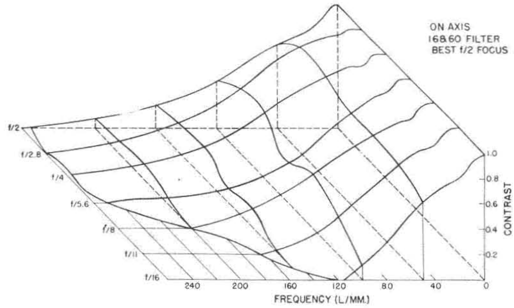

FIG. 4. A 3-dimensional plot illustrating the contrast at various spatial frequencies for seven lens stop openings.

has been plotted against two parameters, *f*/ value and spatial frequency. These data were obtained in testing a lens of 58-mm focal length, on axis, at the best *f*/2 focus, in a spectral range passed by Wratten filters 16 and 60 in combination. Figure 5 shows the results of two tests through focus. The first test measured image contrast of two spatial frequency line patterns at both radial and tangential line orientations, illustrated by the four curves. Results of the second test are shown at the top. In this test, the target was replaced by a pin hole, and photographs were made at the same focal positions of the resultant star images. These data were obtained from the image of a lens of 32 mm. focal-length at a stop opening of *f*/4.5, and at 15 degrees off axis.

The intersections of the radial (solid lines) and tangential (dotted lines) curves for each spatial frequency locate the approximate position of best focus. The star image in the top strip at focal position 0.5—this is almost at the intersection of the radial and tangential curves for the finer lines—is of such shape that a circle surrounding the entire pattern would be smaller than one around any of the other star images, thus showing the highest concentration of light. This result agrees with findings made in studies of spot diagrams.[3]

Figure 6 is a comparison between contrast, as measured in the aerial image, and best definition, as determined by photographs made in the same focal-plane. The horizontal row of traces (center) shows the raw data as

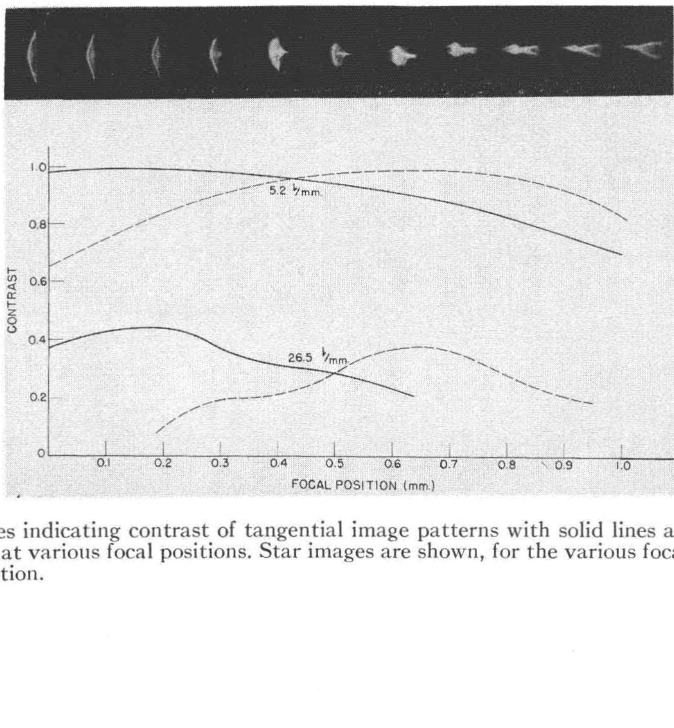

FIG. 5. Curves indicating contrast of tangential image patterns with solid lines and radial patterns with dashed lines at various focal positions. Star images are shown, for the various focal positions, at the top of the illustration.

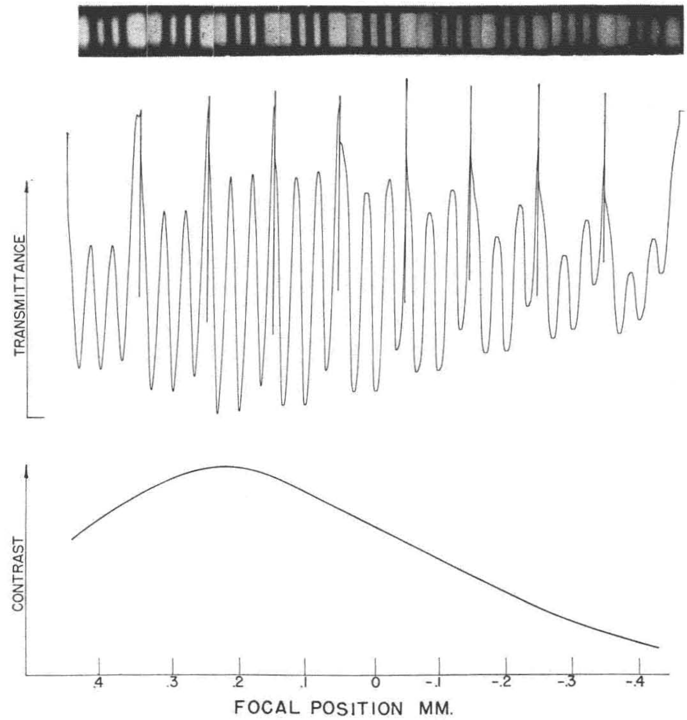

FIG. 6. A comparison on a common focal position scale of contrast (bottom curve) which was computed from recorder traces of middle row and photographs of the image of a 3-line target pattern (top row) made at the same focal positions.

traced by the recorder, and was made by repeated scans of the same three-line frequency pattern. The bottom curve indicates the contrast at various focal positions, as determined from the traces. The row of photographs arranged across the top of the illustration show how the three-line, square-wave pattern appears to the eye as it is scanned by the slit. A comparison of the contrast curve with the photographs shows that the position of maximum contrast differs from the focal position of best definition for a line spacing of 11.1 lines/mm.

This discrepancy between position of highest contrast and best definition exists only in a spatial frequency area somewhat removed from the limit of resolution; near this limit, the two focal positions are coincident. Apparently, the reason for this phenomenon is: When the square wave pattern in the image is degraded because of a small departure from best focus, it approaches in wave form the fundamental term in the series representation, the third harmonic being unresolved. In Figure 6, the position of best definition is indicated by a wave form more nearly resembling a square-wave with flat tops although of lower amplitude.

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