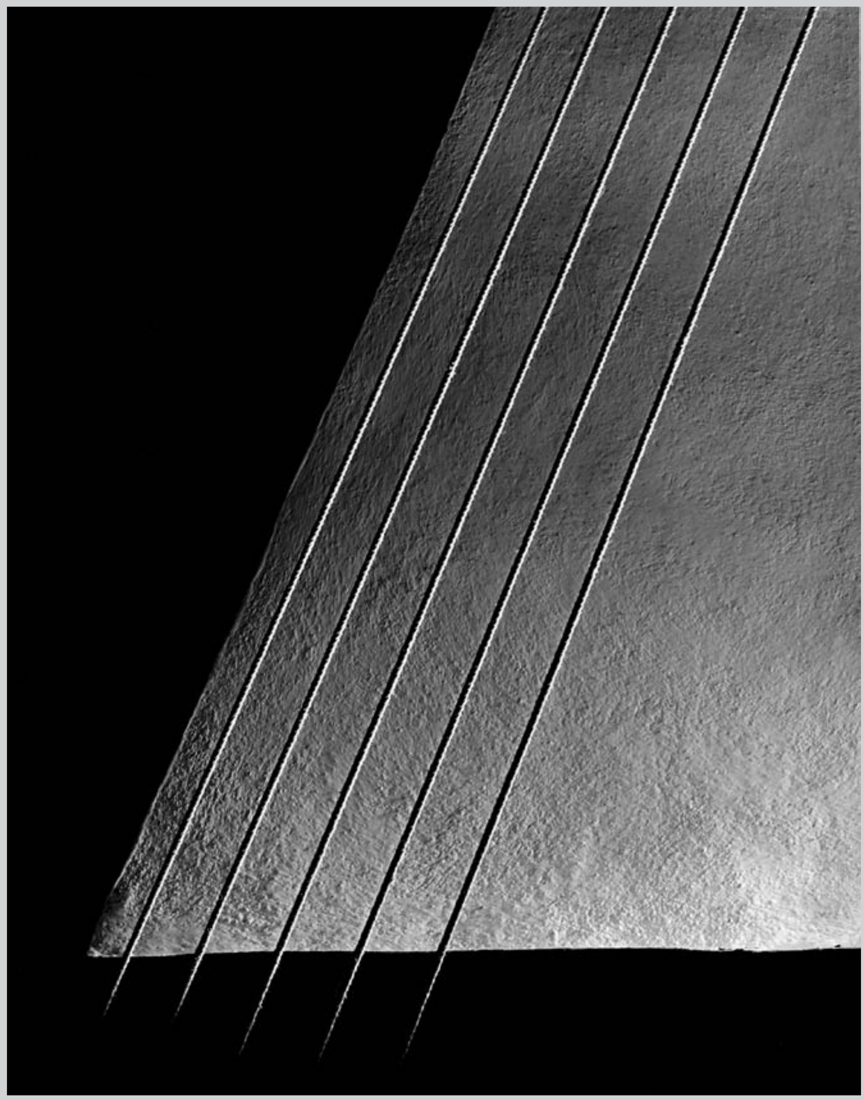
Black-and-White Reciprocity Departure Revisited

by **Howard Bond**

Most photographers know that when the light reaching photographic film is dim enough for the meter to suggest times of a second or longer, the reciprocal relationship between light intensity and exposure time breaks down. As a result, times must be increased to obtain the desired density in shadow areas. Those who think in Zone System terms want to know increases in exposure times that will keep the density of Zone III constant. Making a correction by opening the aperture—as sometimes suggested—doesn't seem useful, since it changes the amount of reciprocity departure that needs correcting. Even if it were practical, I wouldn't do it. I would use the largest aperture that provides adequate depth of field. The exposure time in question is the one the meter indicated for this aperture.



Five Ropes, Steeple Bumpstead, England, *1983. Kodak Royal Pan, ½ stop closeup correction, Zone II pre-exposure, 200 seconds indicated, exposed 45 minutes at ƒ64½, N–3 development. If this photograph were repeated now, an indicated exposure of 200 seconds would require only 6:30 with T-Max 400 or 13:34 with HP-5+, and no pre-exposure.*

Film manufacturers could provide tables giving the time to actually use for any time the meter indicates, but the two I'm familiar with—Kodak and Ilford—don't. Nor do they provide tables showing how much, if any, the high zones are elevated when longer times are given.

If you use the chart from my article "Adjusting Effective Film Speed," (*PT*, Nov/Dec '02), please discard it. It was for Kodak films manufactured in their old facilities. Also, Ilford's 400 Delta is no longer offered in sheet film sizes, and HP-5 has become HP-5+. The corrections for the Ilford films in that chart were based on an obsolete curve Ilford supplied. With some reluctance—I feel this work should have been done by the manufacturers—I spent well over a month and about 300 sheets of film to produce a new chart. I'm pleased to report that departure from the reciprocity relationship when long exposures are needed is a much smaller problem than it was 20 years ago.

For the purposes of this article, Kodak and Ilford supplied me with sheet film to test in early 2003. The Kodak film was made in their new facility.

The next section describes the procedures I used. If you don't expect to use them to investigate another film, or aren't interested in the details, skip to **results**, where the new material is presented.

Procedures

Please bear in mind that the high-numbered steps on the step tablet have the most density and deliver the least exposure to the film positive.

I made contact prints of a 5-inch step tablet (30 steps, increments nominally .10) on film by placing the step tablet in the film holder with the film and exposing in a camera. The white mount board target was lit by two blue photoflood bulbs. The distance from the lights to the target was adjusted to obtain a Zone III exposure through step 20 (density 1.96) for ISO 100 films, or step 23 (density 2.28) for faster films. A Pentax model V (moving needle) spot meter was used because it reveals tiny variations in light, rather than the $^1/_3$-stop increments of the digital Pentax.

Apertures from *f*/5.6 to *f*/64 accompanied indicated times of 1,2,4,...,120 seconds. After setting the light one stop dimmer, *f*/64 was used for 240 seconds. I was concerned that the f-stops marked on the lens might not be accurately spaced, and soon suspected this was true of my 180mm lens. I switched to my 210mm Fujinon W, which proved quite accurate. These lenses were chosen because both have equally and widely spaced f-stop markings.

Adjusting the camera-to-target distance

I used a 5×7 camera with a 4×5 back. The camera-to-target distance was adjusted so a 4-inch strip of black paper taped to the white mount board target was 2 inches long when focused on the ground glass, requiring a one-stop close-up correction. I then moved the camera closer to the target, which didn't need to be in focus. Along with using a longer-than-normal lens, this allowed the target to be small and easy to light evenly.

Rather than measuring the light on the target and determining the exposure, I needed to work backwards because I knew the exposure I wanted. Step 20 acts as a $6^1/_2$ stop neutral density filter (1.96/.3, where .3 equals one stop). Adding another stop for the close-up correction, I needed to place the light reading from the target on Zone III plus $7^1/_2$ stops, or Zone $X^1/_2$. The meter was set to a film speed of 100 for T-Max 100 and the exposure to 1 second at *f*/5.6. Beside Zone $X^2/_3$ on my meter's dial was a reading of $10^2/_3$, so I adjusted the lights to get a reading from the target of $10^2/_3$. A trial exposure didn't yield as much density as I wanted in Zone III, so I adjusted the lights to get a reading of $11^1/_3$ (corresponding to an effective speed of 64). This produced a Zone III density of .38. Similar Zone III densities were used for the other films, except Tri-X, for which I used .28 because of its longer toe.

A lot of light was striking the camera's interior outside the 4×5 film area, and the low density in Zone III was inflated by flare light. (This routinely happens when we photograph outdoors, but we seldom notice.) I made a shroud in the form of a truncated pyramid from black cardboard, and taped it to the inside of the camera back (Figure 1). The forward end, which reached about halfway to the lens, had strips of black paper that made the opening just large enough for the lens to "see" the whole ground glass. Four more strips halfway down the interior of the shroud shielded the film from light reflected off the inner walls. This worked very well, but it also might have been just as effective to use a target just big enough to fill the film area, surrounded by black.

The parts of the film not covered by the step tablet were very heavily exposed, and some light spilled into what should have been clear margins of the film, making them unsuitable for readings of film-base-plus-fog. To obtain a truly clear area, I applied a piece of black plastic electrical tape to each piece of film before exposing. One end was folded under to make the tape easy to remove and transfer to the next sheet of film. However, this didn't result in a clear area on the faster films, until I stuck a small rectangle of aluminum foil in the middle of the tape.

Ideally, one sheet of each film should be exposed with a sufficiently high shutter speed to avoid any reciprocity depar-

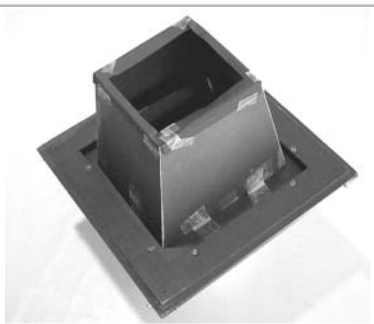


Figure 1. *This is the author's homemade shroud that is placed inside the camera to reduce flare light.*

Figure 2. Conversion from fractional stop change to a factor to apply to exposure time

Fraction of Stop	*Factor for Increase*	*Factor for Decrease*
$^1/_{12}$	1.06	.94
$^1/_6$	1.12	.89
$^1/_4$	1.19	.84
$^1/_3$	1.25	.79
$^5/_{12}$	1.33	.75
$^1/_2$	1.41	.71
$^7/_{12}$	1.5	.67
$^2/_3$	1.59	.63
$^3/_4$	1.68	.60
$^5/_6$	1.78	.56
$^{11}/_{12}$	1.88	.53

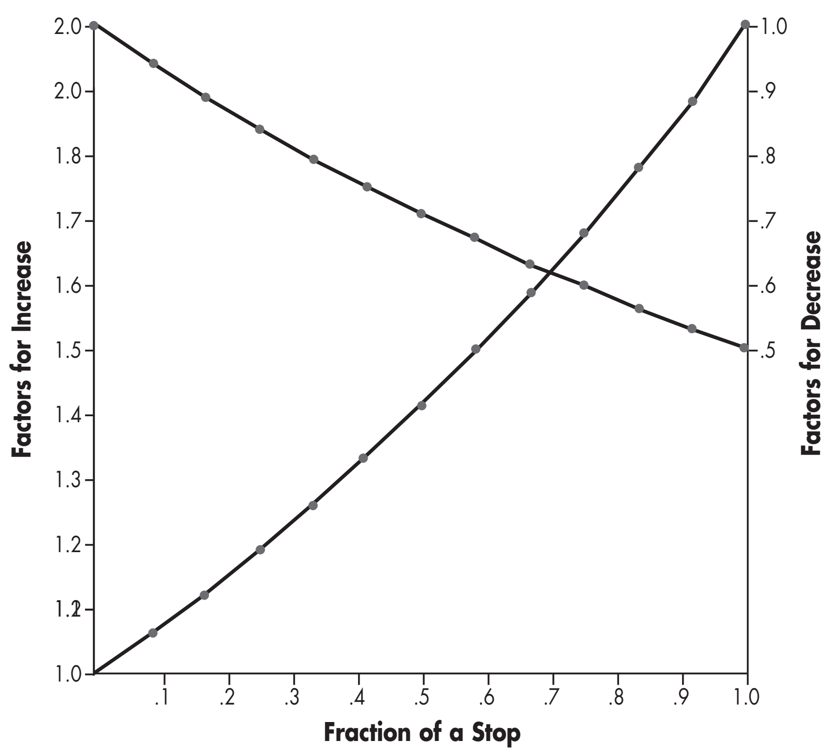


Figure 3. *Small Plot of Figure 2 Data.*

ture in order to get a reference value for Zone III density. With the step tablet densities I used for Zone III, my lights were only bright enough for me to use 1/4 second at $f/5.6$ for this purpose. This was undoubtedly adequate for the four films that needed no correction at one second, but there may have been a bit of reciprocity departure at 1/4 second for Tri-X (which needs a correction when one second is indicated).

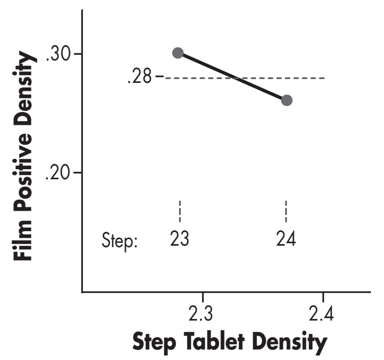


Figure 4. *Example of interpolation between two film positive densities to find step tablet density that would produce the desired film positive density film positive density.*

When you lack the reciprocity information

When investigating a film for which you lack trustworthy reciprocity information, the initial series of exposures can be 1, 2, 4, 8, etc., with no correction. Since many exposures are given to the film by steps other than the one you're using for Zone III, one of them may produce the density you want in Zone III (or you may have to interpolate between two step tablet densities). The difference between this density and the intended density for Zone III indicates the magnitude of the needed correction. Similarly, when you try an exposure that might be correct, this procedure shows how much it should be refined—if at all.

Let d_{III} be the density of the step you're using for Zone III (2.28 in the case of my step 23). If reciprocity departure made some other step yield the film positive density you want (for example, .28), refer to that step's density as d_1. Divide the difference between d_{III} and d_1 by .3 to get the fraction of a stop the exposure should change. Figure 2 relates fractional stop changes to multiplying factors that can be applied to exposure time. Plot the information in Figure 2 (similar to Figure 3, but at a much larger scale) so that a multiplying factor for any fractional stop change can be found accurately. The actual time given is multiplied by this factor to find the corrected time. Remember that the time that was given can be 1,2,4, etc. without correction, it can come from an existing reciprocity correction chart, or from an earlier attempt.

Usually, no step yields exactly .28, and it is necessary to interpolate to find d_1. In the Tri-X example of Figure 4, a trial exposure of 440 seconds was used for an indicated exposure of 120 seconds. This yielded densities on the film positive of .30 from step 23 and .26 from step 24. Interpolating graphically between them, it is seen that the desired .28 film positive density corresponds to a step tablet density of 2.32. The fraction of a stop exposure change needed is $(d_{III}-d_1)/.3 = (2.28-2.32)/.3 = -.133$. The minus sign indicates that the upper curve in a large version of the plot in Figure 3 should be used. This curve shows that .133 stop corresponds to a factor of .912. Multiplying the given time (440 seconds) by .912, the suggested new time is 402 seconds. Use the lower curve in the large version of Figure 3 when $(d_{III}-d_1)$ is positive.

Densities tend to fluctuate from one attempt to another because of small inaccuracies in the measurement of target illumination or exposure time. Since development may vary slightly batch-to-batch, it's a good idea to include a negative exposed at 1 second (corrected in the case of Tri-X) with each batch. If this negative's Zone III density is a little off, compare the Zone III densities from other sheets of film to it, rather than to the intended density. The timing of the one-second exposure is critical. I found it more accurate to open and close the shutter on ticks of my watch than to use the one-second shutter setting.

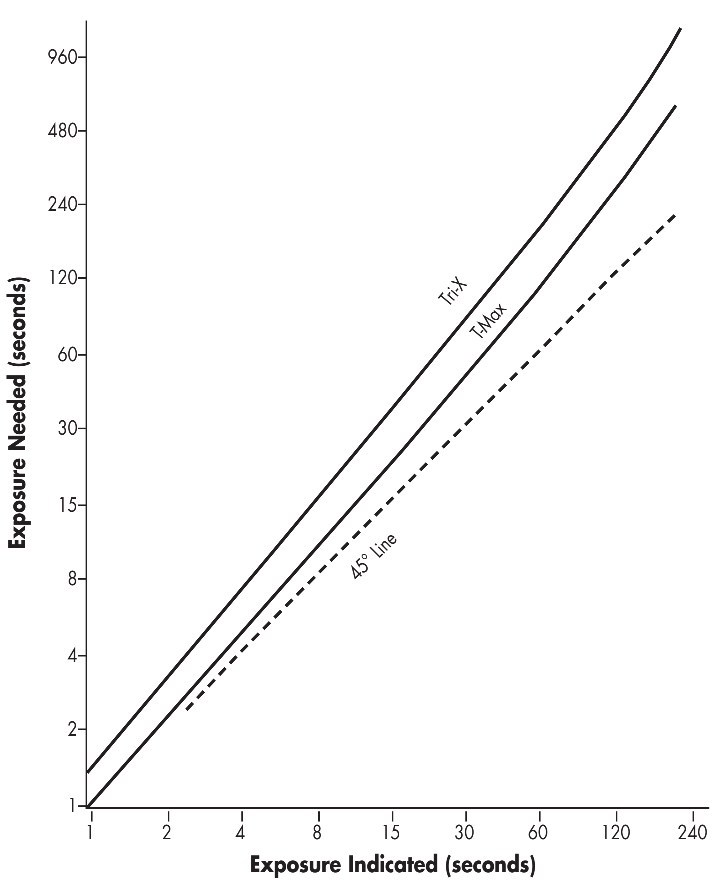


Figure 5. *Examples of log/log plots of exposure needed versus exposure indicated.*

Results

Figure 5 shows log/log plots of exposure time needed versus time indicated. Grid lines are omitted since they would be too close together to be resolved in a reproduction this small. It wasn't feasible to show plots for the other three films; overlap would have been confusing. If these variables were plotted on ordinary graph paper, the plots would be impracticably large and the curvature visible in Figure 5 would not be obvious.

Log/log plots are very helpful when investigating the reciprocity departure of a film. The curve is practically a straight line for indicated exposures as long as 15 or 30 seconds. These plots make it easy to see if an exposure given or obtained from an existing chart is out of line, and they show what exposure might be a better choice. The Tri-X curve was so nearly straight out to 240 seconds indicated (18:16 given), that a slight curvature to the left is seen only near the end. Beyond indicated exposures of about 30 seconds, a curvature to the left was apparent for the other four films. At 240 seconds indicated, the extra exposure beyond what a straight line would have suggested was about $^{1}/_{3}$ stop for 100 Delta and T-Max 400, and $^{3}/_{4}$ stop for T-Max 100 and HP-5+.

Another use for log/log plots is estimating exposure needed when indicated times are longer than those shown in Figure 6. After plotting the times in the chart on log/log paper, a curve can be extended with a French curve to find approximate exposures that are probably better than uneducated guesses. I used two sheets of log/log paper with three horizontal and two vertical cycles, combining them to have four vertical cycles.

In the past, films typically yielded increased density ranges with long exposures. The extra exposure that rendered Zone III as planned was less needed in the high zones, so they were elevated, increasing the density ranges. This situation is now much improved. At 240 seconds indicated, T-Max 400 and 100 Delta showed no elevation of Zone VIII. Tri-X was up slightly, but only slightly more than the typical variation from one trial to another. The Zone VIII densities from HP-5+ and T-Max 100 were elevated about $^{2}/_{3}$ zone. Stating an elevation in terms of zones is very approximate, since the width of a zone (expressed as a range of negative densities) varies greatly with development.

Tri-X findings different from Kodak's data

You may notice that my Tri-X findings are very different from Kodak's. Since at least as long ago as the 1970s, Kodak's Tri-X recommendations have been as follows: at 1, 10, or 100 seconds indicated, give 2, 50, or 1200 seconds (20 minutes), and reduce development 10%, 20%, or 30%. I found it necessary to give the new Tri-X $1^{1}/_{2}$, 17, or 311 seconds (5:11) but no need for reduced development. (Note: Being in disagreement with a manufacturer is not a comfortable situation. I hope Kodak and Ilford, or someone else, will test their newly manufactured films and confirm or refute my results.) Inaccuracies in my exposures and development, and possible variation from one batch of film to another, make my figures somewhat approximate. However, I doubt that such errors add up to a large enough fraction of a zone to be important.

I also had anomalous findings with the new T-Max films. Kodak has T-Max 400 requiring 50% more exposure than T-Max 100 at 100 seconds indicated, whereas I found the opposite—3:05 for T-Max 400 and 3:29 for T-Max 100. At 240 seconds indicated, the difference was more pronounced—9:00 for T-Max 400, and 12:50 for T-Max 100. Kodak doesn't suggest a development change for either film. However, a careful worker might want to take into account the high zone elevation at very long exposures when planning development of T-Max 100.

Ilford curve outdated, too?

In publications dated September 2002 (sent to me in January 2003), Ilford still had a single old curve for correcting reciprocity departure for HP-5+ and 100 Delta. I found the behavior of these films to be quite different from the curve, and also different from one another.

Figure 6 shows the times to give for indicated times as long as 240 seconds, in $^{1}/_{3}$-stop increments. Times in bold type, corresponding to indicated times of 1, 2, 4, ..., 240 seconds, were verified by trying them and seeing how well they fit the curve on a log/log plot. The intermediate times, which are $^{1}/_{3}$-stop increments between whole stop times, were calculated as in the following example. With T-Max 100, indicated times of 8 and 15 seconds should receive 10 and 21 seconds. The difference between these times is 11 seconds. One-third stop more than 10 seconds is 10+.25×11, or 13 seconds. Two-thirds more than 10 seconds is 10+.59×11, or 17 seconds. The factors .25 and .59 for $^{1}/_{3}$ and $^{2}/_{3}$-stop changes come from the table in Figure 2.

Fractions of seconds are given for some times less than 6 seconds. My watch ticks once per second. For a $1^{1}/_{2}$-second exposure, I establish the correct speed by saying, "Oh and 1 and 2 and, etc." with the numbers falling on ticks. Then I do it again, opening the shutter on "Oh" and closing it on "and" after 1. At one second indicated, Tri-X actually needs $1^{1}/_{3}$ seconds, but Figure 5 lists $1^{1}/_{2}$ seconds. I assume readers won't want to try finer divisions than half-seconds.

Clearly, photographers are now in a much more favorable position when departure from the reciprocity relationship necessitates exposure compensation. Films can be chosen that require less additional exposure and little or no change in development. Exposure corrections, when reciprocity departure occurs, could no doubt be found more accurately by the manufacturers. However, my times have produced Zone III densities very near those intended, and the times lie close to a smooth curve in a log/log plot. ■

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Figure 6. *Times to give when the meter indicates exposures of one or more seconds.*

Tri-X	**1.5**	2	2.5	**3**	4	5	**6**	8	10	**12**	17	22	**29**	42	58	**1:18**	1:44	2:19	**3:00**	3:56	5:11	**6:42**	9:36	13:32	**18:16**
HP-5+	**1**	1.5	1.5	**2**	3	4	**5**	7	8	**10**	14	18	**24**	32	42	**54**	1:20	1:55	**2:36**	3:24	4:28	**5:45**	9:04	13:34	**19:00**
100 Delta	**1**	1.5	1.5	**2**	3	3.5	**4.5**	6	7	**9**	12	15	**19**	26	32	**41**	54	72	**1:33**	2:08	2:54	**3:50**	5:13	7:05	**9:20**
Indicated	**1**	•	•	**2**	•	•	**4**	•	•	**8**	•	•	**15**	•	•	**30**	•	•	**60**	•	•	**120**	•	•	**240**
T-Max 400	**1**	1.5	1.5	**2**	2.5	3.5	**4.5**	6	8	**10**	13	17	**21**	28	38	**49**	1:03	1:22	**1:44**	2:18	3:05	**4:00**	5:15	6:57	**9:00**
T-Max 100	**1**	1.5	1.5	**2**	2.5	3.5	**4.5**	6	8	**10**	13	17	**21**	28	38	**49**	1:04	1:24	**1:47**	2:30	3:29	**4:39**	6:42	9:30	**12:50**

Boldface times have been verified. Times at $^{1}/_{3}$ and $^{2}/_{3}$ stop points between them were calculated, but are as accurate as the boldface times. If you don't want to give half seconds, round up to the next whole second. Kodak films were made in their new facilities. All films were obtained for testing in 2003.