Understanding and Using Tilt/Shift Lenses

by Jeff Conrad

Introduction

Camera Movements

In addition to the larger image size, a great advantage of a view camera over most small- and medium-format cameras is the inclusion of camera *movements* that allow adjustment of the lens position relative to the image plane. Two types of movements are usually possible: displacement of the lens parallel to the image plane, and rotation of the lens plane relative to the image plane.

Parallel displacement allows the *line of sight* [1] to be changed without moving the camera back, so that the position of the subject in the image can be adjusted while parallel lines in the subject are kept parallel in the image. In effect, the camera is aimed by adjusting the shift setting. When the shift motion is vertical, it is usually called *rise* or *fall* (or sometimes, *drop*); when the motion is horizontal, it is called *lateral shift* or *cross*. Rising front is often used when photographing tall buildings, to avoid the appearance of them falling over backward; falling front is often used in studio product photography. Lateral shift is sometimes used in both situations.

Rotation of the lens plane allows control of the part of the image that is acceptably sharp. Rotation about a horizontal axis is called *tilt*; rotation about a vertical axis is called *swing*. Tilt, swing, or both are often used when it is otherwise not possible to get sufficient *depth of field* (“DoF”). Without tilt or swing, the DoF extends between two planes parallel to the image plane; it is infinite in height and width but limited in depth, so that only a small part of it is within the camera’s field of view. Tilt, swing, or both give a wedge-shaped DoF that is limited in height or width but potentially infinite in depth; for many scenes, this shape may be a better fit to the region for which sharp rendering is desired. Tilt or swing can also be used to give selective focus for which the zone of sharpness is not parallel to the image plane.

The use of rise/fall and lateral shift is intuitive and usually is easily mastered; the lens displacement is adjusted until the desired image framing is achieved. The use of tilt and swing is less intuitive, and the effects are not as readily visualized; these movements change not only the orientation of the subject plane, but also the orientation and shape of the depth of field. Moreover, when a lens is tilted or swung, focusing the lens has a different effect than without these movements. But with a basic understanding of the principles involved and a bit of practice, it’s reasonably easy to use tilt and swing effectively.

Tilt/Shift Lenses

Tilt/shift lenses provide functionality similar to view camera movements, although the range of movements is more limited and setting the movements is often not as convenient.

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[1] The line of sight extends between the center of the image area and the center of the lens’s *exit pupil*, which is the *center of projection* for the image. A good illustration is given in Ray (2000, 57–58). The line of sight is also known as the *line of vision* or the *visual axis*.

It is not possible to independently set tilt and swing, or rise and shift, but the tilt/shift mechanisms on the lenses can be rotated about the lens axes to allow, in effect, combined rise and shift and combined tilt and swing. Canon and Nikon tilt/shift lenses are configured with the tilt and shift movements at right angles, i.e., one can employ tilt and lateral shift, or swing and rise/fall. The lenses can be reconfigured so that the movements are aligned, i.e., allowing tilt and rise/fall or swing and lateral shift. On the Hartblei Super-Rotator lenses and the Canon TS-E 17 mm and the TS-E 24 mm II, the tilt and shift movements can be rotated independently.

Although view-camera users often distinguish between horizontal and vertical movements, small-format camera users and manufacturers typically do not, referring to both rise/fall and shift as "shift," and to both tilt and swing as "tilt."

Plane of Focus with a Tilted Lens

On a camera without movements, the lens axis is perpendicular to the image plane and the plane of focus ("PoF"). When the lens is rotated relative to the image plane, the PoF is also rotated relative to the image plane. At the beginning of the 20th century, Jules Carpentier and Theodor Scheimpflug discovered that the PoF, a plane passing through the center of the lens, and the image plane intersect on a common line. This phenomenon has become known as the Scheimpflug principle, although it actually follows from a theorem in projective geometry named for French mathematician Girard Desargues (1591–1661). It also is easily derived from simple analytical geometry.

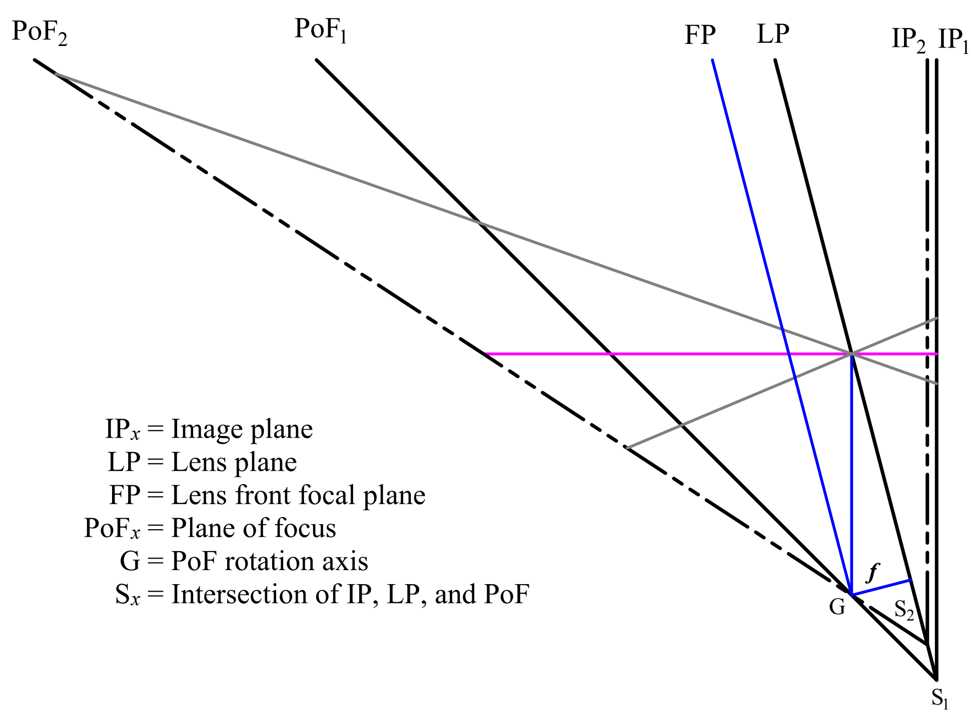

Figure 1. Rotation of the Plane of Focus

Scheimpflug also discovered that the PoF, a plane parallel to the image plane passing through the center of the lens, and the lens's front focal plane have a common intersection, indicated as G in Figure 1. The PoF rotates about this axis as the camera is focused, as illustrated in Figure 1: as the image plane is moved from IP_1 to IP_2, the PoF rotates about the axis G from position PoF_1 to position PoF_2. Because of this behavior, Merklinger (1993a) has called this intersection the "hinge line." Strictly, the PoF rotates about this axis only when focus is accomplished by moving the image plane, which isn't possible with a tilt/shift lens. However, except for close-up work, the difference between focusing with the lens and with the camera back is negligible.

Although this behavior was described in Scheimpflug (1904), it received little subsequent mention, at least in English-language publications, prior to Merklinger (1993a).

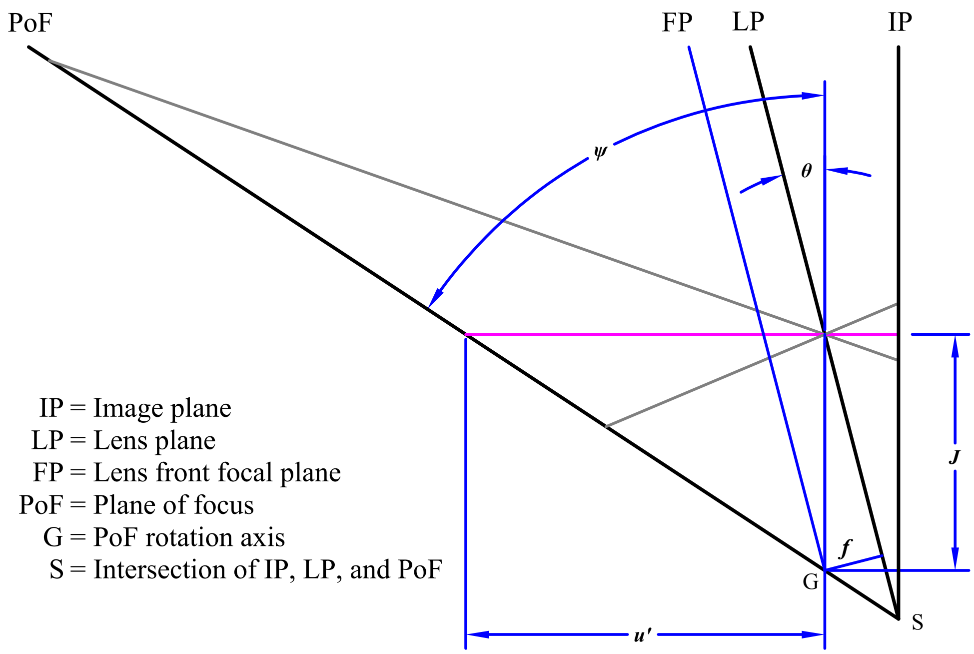

Figure 2. Rotation-Axis Distance and Angle of the Plane of Focus

If the lens has focal length f and the lens plane is tilted at an angle θ to the image plane, the distance J from the center of the lens to the PoF rotation axis G is given by

$$J = \frac{f}{\sin\theta}; \tag{1}$$

the distance J decreases as the tilt is increased. The position of the axis G is fixed by the tilt; the orientation of the PoF is then set by adjusting focus. If u' is the distance along the line of sight from the center of the lens to the PoF, the angle ψ between the image plane and the PoF is given by

$$\tan\psi = \frac{u'}{f}\sin\theta\,. \tag{2}$$

The angle of the PoF thus increases with increasing tilt and focus distance; at infinity focus, the PoF is perpendicular to the image plane with any non-zero tilt. Because of mechanical limitations, actual maximum rotation of the PoF with most tilt/shift lenses is slightly less than 90°. Note that the distance u' along the line of sight is *not* the distance indicated by the lens distance scale; the latter is measured perpendicular to the lens plane, and extends from the image plane to the object. When the lens is tilted, the indicated distances usually have little meaning.

In the two-dimensional representations above, the PoF appears as a line. One point and an angle suffice to specify any straight line; in the case of a tilted lens, the point is determined by the tilt, and the angle is set by adjusting focus. Together, they fix the position of the PoF.

To summarize: with an untilted lens, the position of the PoF is controlled by the focusing ring, which varies the distance of the PoF from the camera. When the lens is tilted,

- The tilt determines the distance from the camera to the PoF rotation axis.
- The focus determines the orientation of the PoF.

In combination, tilt and focus determine the position of the PoF.

Depth of Field with a Tilted Lens

Without movements, the planes that define the near and far limits of the DoF are perpendicular to the lens axis. When considerable DoF is required, even the smallest aperture may not be sufficient to render the entire scene acceptably sharp. With a tilted lens, the planes that define the near and far limits of depth of field are rotated with respect to the image plane; these planes intersect at the PoF rotation axis, forming a wedge-shaped DoF. If the wedge-shaped DoF is a good match to the scene, it may be possible to have the entire scene acceptably sharp using a smaller lens *f*-number than would be needed if the lens were not tilted.

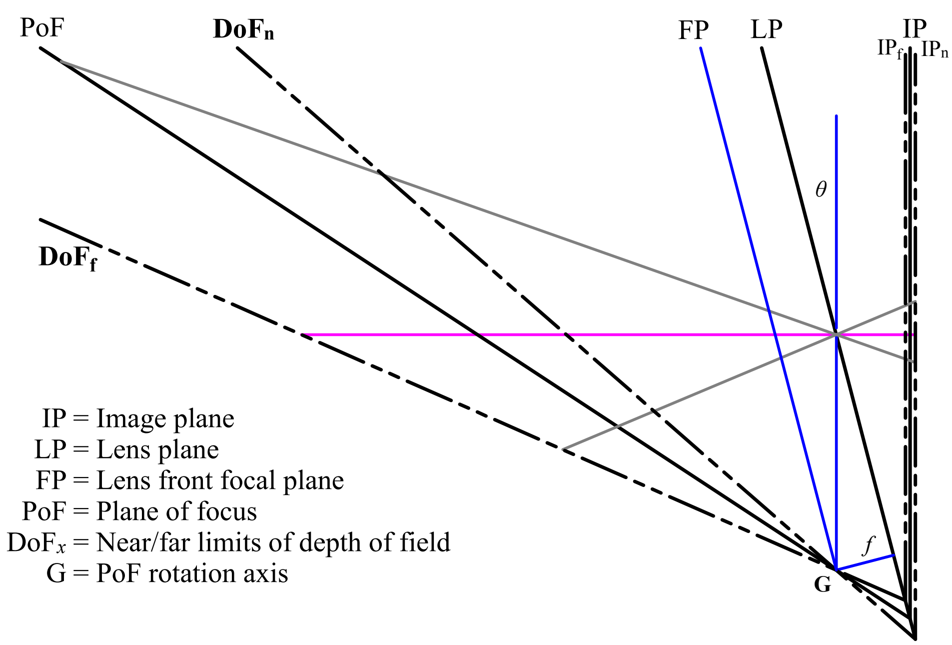

Figure 3. Depth of Field with Tilted Lens

The DoF for a tilted lens is illustrated in Figure 3: it is the region to the left of G, bounded by the planes DoF_n and DoF_f, with the apex of the DoF wedge at the PoF rotation axis. The nature of the DoF has generally been given only cursory treatment, and prior to Merklinger (1993b) and Tillmanns (1997, 71), was often described incorrectly.[2]

Formulas for calculating DoF with a tilted lens are given in the Appendix.

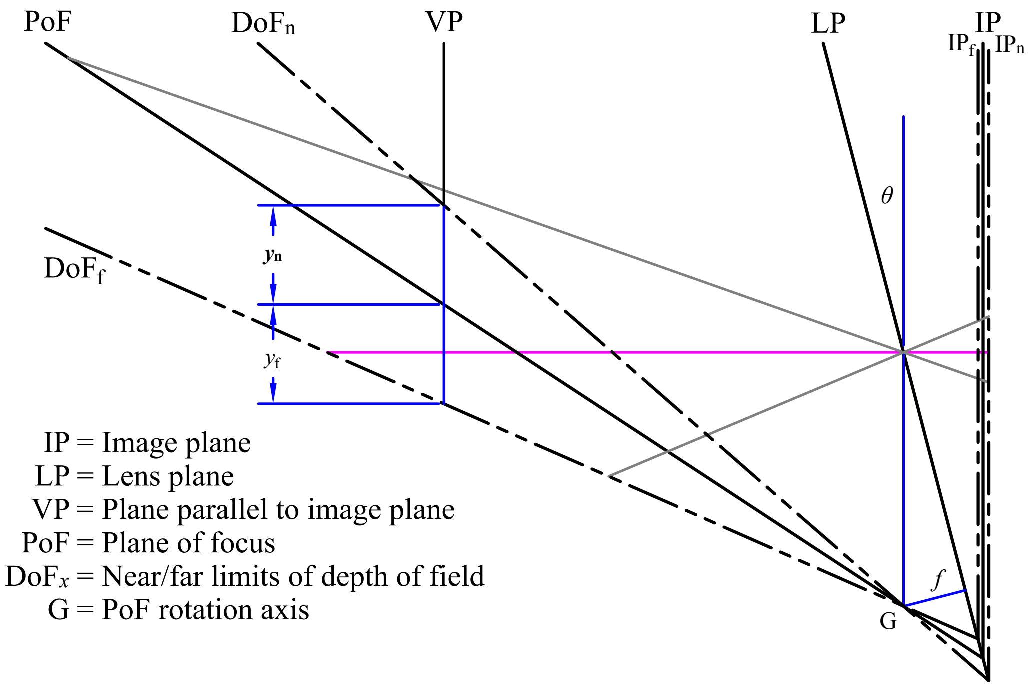

Figure 4. DoF on Plane Parallel to Image Plane

The DoF is distributed equally about the PoF on any plane parallel to the image plane, as illustrated in Figure 4: on the plane VP, the distances y_n and y_f on each side of the PoF are equal. This characteristic can be helpful in setting the PoF to the optimal position within the region that is to be sharp. Note, however, that the angular DoF is *not* equal on both sides of the PoF. Fortunately, it's usually easier to estimate the midpoint of an object parallel to the image plane than it is to estimate the middle of an angle.

The position and shape of the DoF with a tilted lens are thus determined by three controls:

- The tilt determines the distance from the camera to the apex of the DoF wedge.
- The focus determines the orientation of the DoF wedge.
- The lens *f*-number determines the angular DoF.

Tilt and Swing

Once the camera position and lens have been chosen, setting the camera to give the desired DoF entails several steps; for simplicity, the initial discussion will cover only tilt, but the procedure is similar for setting swing. The steps are as follows:

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[2] Tillmanns states that prior to development of the Sinar e camera (released in 1988), the DoF wedge was thought to extend to the line of intersection of the object, lens, and image planes.

1. Determine the best position for the DoF wedge.
2. Fix the position of the apex of the DoF wedge by setting the tilt.
3. Fix the orientation of the DoF wedge by setting the focus.
4. Fix the angle at the apex of the DoF wedge (i.e., the angular DoF) by setting the lens *f*-number.

The first step is by far the most challenging. The last three are straightforward and essentially mechanical once the position of the DoF wedge has been decided. Because the last three steps are sometimes needed for determining best position for the DoF wedge, they will be covered first.

Setting Tilt

If a subject is essentially flat, such as a chess board or field of flowers on flat terrain, the PoF is simply set to coincide with the subject plane, and everything will be sharp. If a scene includes significant height, however, some thought must be given to how to best align the DoF wedge with the scene. Setting the position of the PoF is straightforward; deciding what that position *should be* is not always as simple. It's possible to simply fiddle with the tilt, focus, and *f*-number until everything appears sharp, but in most cases, a more systematic approach will give better results with less time and effort.

If the PoF rotation axis were within the field of view, it would be a simple matter to set the tilt visually until that point was sharp, and then adjust focus to align the PoF with another point in the scene. Unfortunately, the rotation axis is far outside the field of view, so a different procedure is needed. The easiest way to set the tilt is usually to choose two points in the scene, one near and one far, and adjust tilt and focus so that the PoF passes through those points. This can be done using any of several different methods.

Calculating Tilt from the Distance to the PoF Rotation Axis

Some photographers (Merklinger 1996) find it easy to envision the best position for the PoF rotation axis, and use Eq. (1) to calculate the tilt from the distance from that axis to the lens; focus is then adjusted until a suitable far point is sharp. If the subject is flat, the the rotation axis should lie in the subject plane, and the distance from the lens can sometimes be directly measured. If the subject isn't flat, the best position for the rotation axis may be less obvious.

Calculating the rotation-axis distance can also serve as a quick sanity check for tilt settings. With a short-focus lens, a little tilt goes a long way. For example, with a 24 mm lens, a tilt of 8° places the rotation axis 172 mm below the lens. If the rotation axis is to coincide with the plane of the chess board, the chess board must be 172 mm below the camera. For the PoF to coincide with the ground plane with the camera positioned at normal eye level, considerably less tilt will often suffice. For example, with a 24 mm lens and a camera height of 1.5 m, a tilt of slightly less than 1° is needed to place the rotation axis at ground level. A common error for photographers new to camera movements is setting too much tilt.

Adjusting Tilt and Focus Simultaneously

Another approach is to simultaneously adjust the tilt and focus until the near and far points are sharp. This method has long been used by many large-format photographers, especially with cameras that have base tilts.

Howard Bond's "Focus/Check" Method

Bond (1998) has described a method that he calls "Focus/Check," in which the tilt is set, focus is adjusted while observing the effect on sharpness, and if necessary, the process repeated with a different value of tilt. Although still trial and error, it is arguably more systematic. That method, in essence, is as follows:

A. Select a near point and a far point through which the plane of focus is to pass. The two points should contain sufficient detail to enable determination of sharp focus. Ideally, the two points would be as far apart as possible on the focusing screen, but they need not be the same distances from the center of the screen. The near and far points in the procedure below can be interchanged if desired.

B. Choose an initial value for the tilt, and repeat until the sharpness of the near point does not change:

   1. Focus on the far point.
   2. Slowly decrease the focus distance (i.e., focus closer); then
      - If the near point becomes sharper, increase the tilt; or
      - If the near point becomes less sharp, decrease the tilt; or,
      - If the change in the sharpness of the near point is difficult to determine,
        a. Refocus on the far point.
        b. Slowly *increase* the focus distance; then
           - If the near point becomes sharper, decrease the tilt; or,
           - If the near point becomes less sharp, increase the tilt.

This procedure usually requires only a few iterations to determine acceptable settings, regardless of the initial value of the tilt. The procedure can be reversed by first setting focus and adjusting tilt, but on the most tilt/shift lenses, the smoothness and precision of the focusing helicoid are greater than those of the tilt adjustment, so it's usually easier to use the procedure as described.

Determining Focus and *f*-number

Once the tilt is set, the *f*-number and final position of the PoF can be determined using the lens DoF and distance scales if the DoF scale is sufficiently legible. The procedure is essentially the same as "zone focusing" with an untilted lens, in which the distance and DoF scales are used to determine a focus distance and *f*-number that will have the DoF extend between two specified distances. There is one important difference when the lens is tilted, however; changing focus changes the *angle* of the plane of focus rather than the *distance* of the plane of focus from the camera, so the indicated distances no longer correspond to camera–object distances. Consequently, the near and far points must be determined visually by adjusting focus rather than by using the marked values on the distance scale. The procedure is nonetheless straightforward:

1. Focus on the point at the least angular distance from the of the image plane; note the marked distance.
2. Focus on the point at the greatest angular distance from the image plane; note the marked distance.

3. Set the focus so that it is halfway between the two marked distances noted above.
4. On the depth-of-field scale, find an *f*-number whose marks are on or just outside the marked near and far distances; set the lens to that *f*-number.

As the lens is focused, the plane of focus rotates rather than moving toward or away from the camera; because of this, the points at the least and greatest angular distances from the image plane may not immediately be obvious, and finding them may require several attempts. The "near" point may actually be much farther from the camera than the "far" point, and the limiting points may change as the tilt is changed.

Because the lens distance scales are marked to indicate object distances rather than image distances, the progression is nonlinear, and the scales are more difficult to read and interpolate to high precision. Determining the *f*-number would be much easier if the lenses also included linear scales with closely spaced markings to be used only for that purpose; unfortunately, no manufacturers provide such scales.

Despite indication to the contrary in the Canon and Nikon instruction manuals, the DoF scales work fine when the lens is tilted, *provided that* the near and far points are determined visually by adjusting focus rather than by estimating distances and finding the closest marked distances on the lens distance scale. The required *f*-number is proportional to the *focus spread*[3] whether or not the lens is tilted, so that rotation of the focusing ring between the near and far points is proportional to the focus spread. The *f*-number determined using the lens DoF scale is fine when the subject distance is large in comparison with the lens focal length, but for close-up work, requires correction as described in the Appendix.

On some tilt/shift lenses, especially newer ones from both Canon and Nikon, the DoF scales are so small and sparsely marked that they can be difficult to read to sufficient accuracy. If the DoF scale proves unusable, focus can be adjusted until the PoF passes through the approximate vertical middle of a distant object; if the tilt has been set reasonably, the near point on the PoF will be close to where it should be. The *f*-number must then be determined visually with the lens stopped down to working aperture; the most efficient approach is probably to choose one point on the near limit of DoF and one on the far limit, and adjust the aperture until both points are acceptably sharp.

Determining the Best Position for the DoF Wedge

If a scene is essentially flat, the initial setting of the PoF will suffice to get everything sharp. But setting the PoF to pass through two points will only ensure that those points are acceptably sharp. If a scene has height as well as depth, it is impossible to have everything in exact focus, and acceptable overall sharpness relies on the DoF, much as a camera without tilt. If a scene includes height near the camera (e.g., tall trees in the foreground), tilt may not provide much benefit. But if the scene height increases with distance from the camera (e.g., a field of flowers with mountains in the distance), the region of interest may be a good match to the wedge-shaped DoF, and it may be possible to achieve the desired sharpness with a smaller *f*-number than would be required without tilting the lens.

If tilt is to afford full advantage, however, it must be set to its optimal value. If a scene has minimal height, the situation is essentially the same as that for a planar subject; the

[3] The focus spread is the difference between the image distances that correspond to the near and far limits of DoF; when the lens is tilted, these limits are angular.

position for the PoF is fairly obvious, and tilt can provide significant benefit if the PoF is reasonably close to its optimal position. If a scene includes significant height, the best position for the PoF is less obvious, and unless the tilt is very close to its optimal value, there may be little or no benefit. Both cases will be examined.

Minimal Height, or Height Far from the Camera

A classic application of tilt is a scene with flowers in the foreground and mountains or trees in the background.

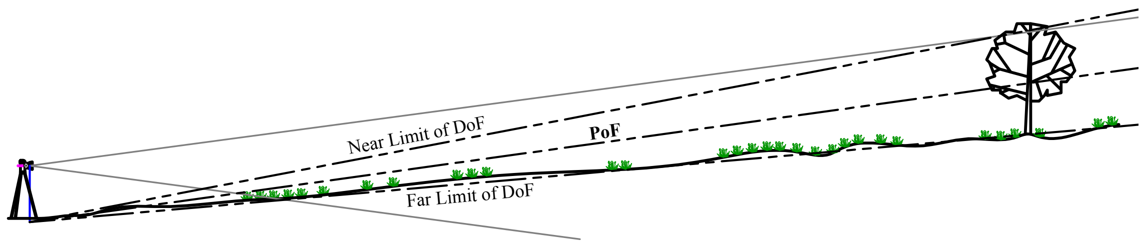

Figure 5. Flowers and Distant Tree

In the scene shown in Figure 5, the distance to the near flower is about 20 ft, the distance to the base of the distant tree is about 95 ft, and the distance to the far flower is about 103 ft. The ground at the base of the tree is about 8 ft above the camera; this is similar to a situation on level ground in which the camera is pointed slightly downward. The camera is 5 ft above the ground.

The required tilt, focus, and *f*-number can be calculated from the geometry of the diagram using Eqs. (A1) and (A2). Though straightforward, the calculations are tedious, and consequently, the details are omitted from the discussion that follows. In the field, of course, the diagrams are not available, and some parameters, such as the position of the PoF rotation axis and the angles of the PoF and near and far limits of DoF, are not easily measured. Fortunately, the tilt can be set visually using a method such as Bond's, and the focus and *f*-number determined using the lens distance and DoF scales, as discussed in the section Determining Focus and *f*-number.

If the camera is full-frame 35 mm with a 90 mm tilt/shift lens in landscape orientation, achieving the desired DoF without tilt requires about *f*/14, which may be a problem if there is any wind. The optimal position for the PoF would have it pass through the middle of the near flower and the middle of the tree. The middle of the tree is probably suitable for focusing, but the middle of near flower stem may be occluded by the flower itself, and may be difficult to use as a focusing target; choosing the top of the flower for the near point of the PoF may be a reasonable compromise. Using a tilt of 3° to pass the PoF through the top of the near flower and the approximate middle of the tree, everything of interest can be placed within the DoF at about *f*/7.1, a two-step advantage over not using tilt, while providing slightly better sharpness on the near flower. If the DoF is to extend to infinity, achieving it without tilt requires *f*/19, while the *f*-number with tilt is unchanged, so the advantage of using tilt increases to 2⅔ steps.

In theory, the tilt could be set to 2.5° to put the near limit of DoF at the top of the near flower and the edge of the field of view at the tree, allowing an aperture of about *f*/6.3. But in most cases, there would be little advantage in doing so, and from a practical standpoint, the difference would be nearly impossible to discern on the lens's DoF scale, which is marked only at *f*/16 and *f*/32; a reasonable approach might be to visually interpolate a value of *f*/8. The position of the PoF should be easy to set using the top of the near flower and the middle of the tree as focusing points.

Height near the Camera

Setting the tilt may not be as simple if a scene includes significant height near the camera. The best position for the DoF wedge is not always obvious, and there may not be convenient near and far focusing points to use in setting the PoF. And in some cases, tilt may afford little or no advantage.

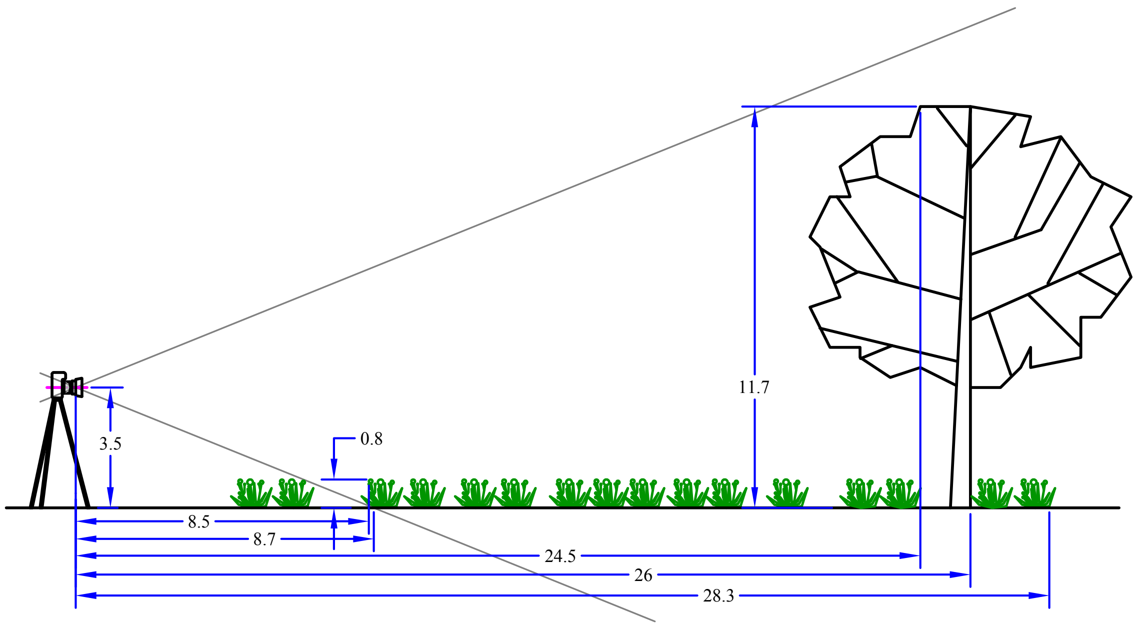

Figure 6. Flowers and Tree

Consider a scene such as that in Figure 6, a field of flowers with one or more nearby trees for a background (e.g., an orchard in spring). The region of interest is wedge shaped, but the height is fairly significant. A full-frame 35 mm camera with a 45 mm tilt/shift lens is positioned fairly close to the ground with the long format dimension vertical (i.e., portrait orientation); all dimensions are in feet. Assume that nothing beyond the far flower needs to be sharp.

Without tilt, getting everything from the near flower to the back of the distant flower within the DoF requires an aperture of approximately *f*/8, which is acceptable in most situations, except perhaps a windy, overcast day. Can using tilt allow a slightly larger aperture and shorter exposure time?

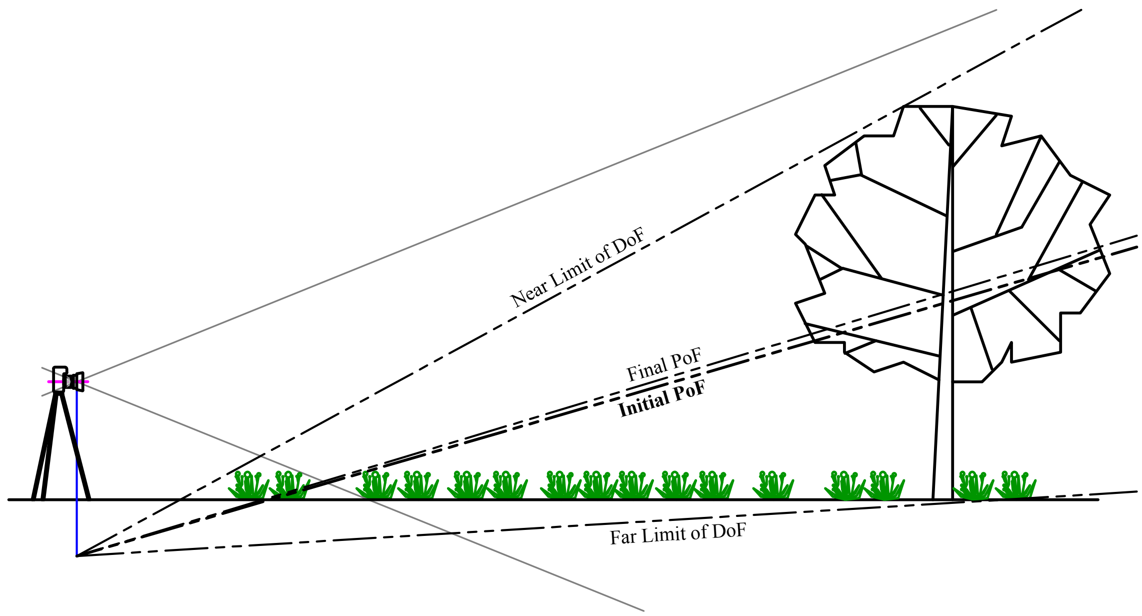

Figure 7. Flowers and Tree with PoF through Near Flower

The DoF is equally distributed about the PoF on any line parallel to the image plane. If the optimal DoF wedge coincided with the region to be sharp, it usually would be a simple matter to set the PoF so that it passed through the vertical midpoints of a near and far object in the scene. But that seldom is the case; although the DoF wedge is often a close fit to the distant parts of a scene, the best position for the apex of the DoF wedge is usually below ground, and much of the DoF around a near object may also be below ground and perhaps even outside the camera's field of view. Moreover, as in this example, the near object may occupy only a small part of the height of the DoF wedge, so that the true midpoint of that height would be difficult to estimate even if the entire height were visible. Consequently, the midpoint of a near object may not be a practical focusing target, and a different approach is needed.

As in the previous example, a reasonable compromise might be to set the tilt by passing the PoF through the top of the near flower and the middle of the tree, as shown in Figure 7; the flower and tree would provide good visual targets for adjusting the PoF (provided the tree wasn't too dense). The resulting tilt would be 1.7°. Determining the final focus using the lens DoF scale would place the PoF slightly above the initial position, but the difference would probably be insignificant and essentially unnoticeable on the lens DoF scale. The desired DoF can be achieved with an aperture of about *f*/9.5, but this is a half step smaller than would be needed without tilt.

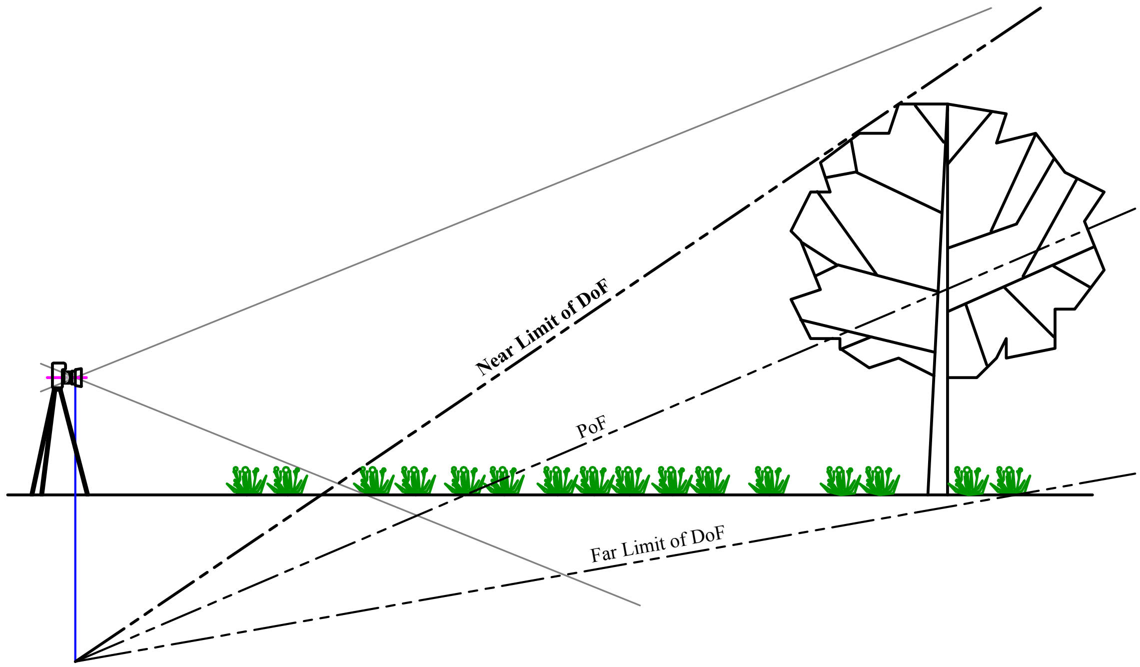

Figure 8. Flowers and Tree with Tilt Set from Near Limit of DoF

A glance at Figure 7 reveals that a fair amount of the DoF on the near side of the PoF is wasted. This wasted DoF can be eliminated by having the near limit of DoF just include the objects of interest. The PoF and the planes defining the near and far limits of DoF all pass through the same axis, so the tilt determined by using any one of them to set the initial PoF will be the same. Once the tilt is set, the final PoF can be determined using the lens DoF scales, as was done previously. The desired near limit of DoF will usually provide good visual targets for setting the initial PoF.

Figure 8 shows the tilt set by initially passing the PoF through the top of the near flower and the edge of the tree; the DoF then just includes the flower and the tree. The required tilt is only 1°. The final PoF can then be set by focusing on the middle of the tree or by using the lens DoF scale. This setting allows an aperture of *f*/5.6, a full step larger than required without using tilt. On a windy day, it could be the difference between getting a sharp image and having to settle for a slight motion blur. Of course, because the lens DoF scale has no markings for apertures larger than *f*/8, accurately reading the required *f*-number could be a challenge.

Passing the final PoF through the near object of interest, as shown in Figure 7, has the advantage of ensuring that the flower is sharp if there are slight focusing errors or the chosen *f*-number is too small. And passing the PoF through an object of interest ensures the sharpest rendering of that object of any approach discussed, even when focusing is always exact. It's also arguably the most intuitive approach when the tilt is set visually. But it often doesn't lead to the smallest *f*-number, and in some cases provides no benefit whatsoever. In the example in Figures 6–11, passing the PoF through the near flower requires an *f*-number 1½ steps greater than with optimal tilt and ½ step greater than required without any tilt.

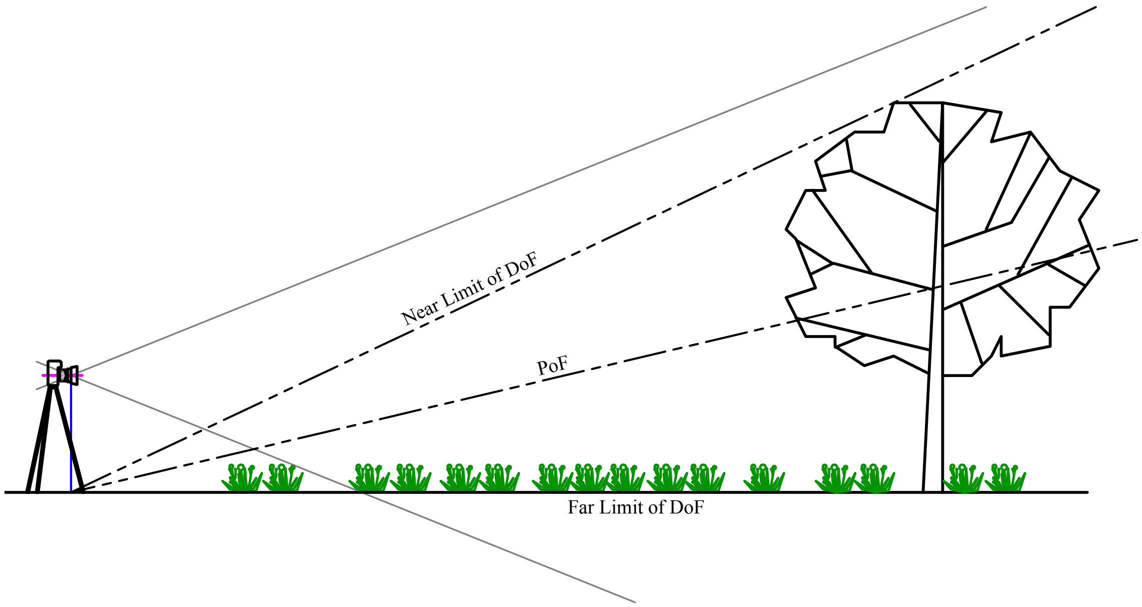

Figure 9. Flowers and Tree with PoF Rotation Axis at Ground

Setting the tilt as shown in Figure 8 eliminates the wasted DoF on the near side of the PoF, but leaves a fair amount of excess DoF on the far side. Placing the apex of the DoF wedge at ground level, as shown in Figure 9, eliminates the excess DoF on the far side of the PoF. The required tilt is easily calculated from the lens focal length and the camera height to be about 2.4°, or set visually to make the ground plane sharp. The DoF extends to infinity (which could be a problem if the distant background is distracting), and the far limit of DoF just includes the objects that are to be sharp. But there is even more wasted DoF on the near side of the PoF than in Figure 7, and getting everything within the DoF requires an aperture of approximately $f/13$, which is 1⅓ steps smaller than if no tilt were used.

If the picture did not include the tree, placing the DoF wedge apex on the ground would be fine, requiring an aperture of about $f/2.8$. In that case, both the near and far DoF limits would just include the objects of interest. The near limit of DoF would be defined solely by the top of the near flower, so there would be no second focusing target, and the tilt would need to be set by aligning the PoF with the ground. Of course, with most of the frame empty, that case would make for a strange picture; in practice, the camera would probably be pointed down, and perhaps positioned closer to the ground.

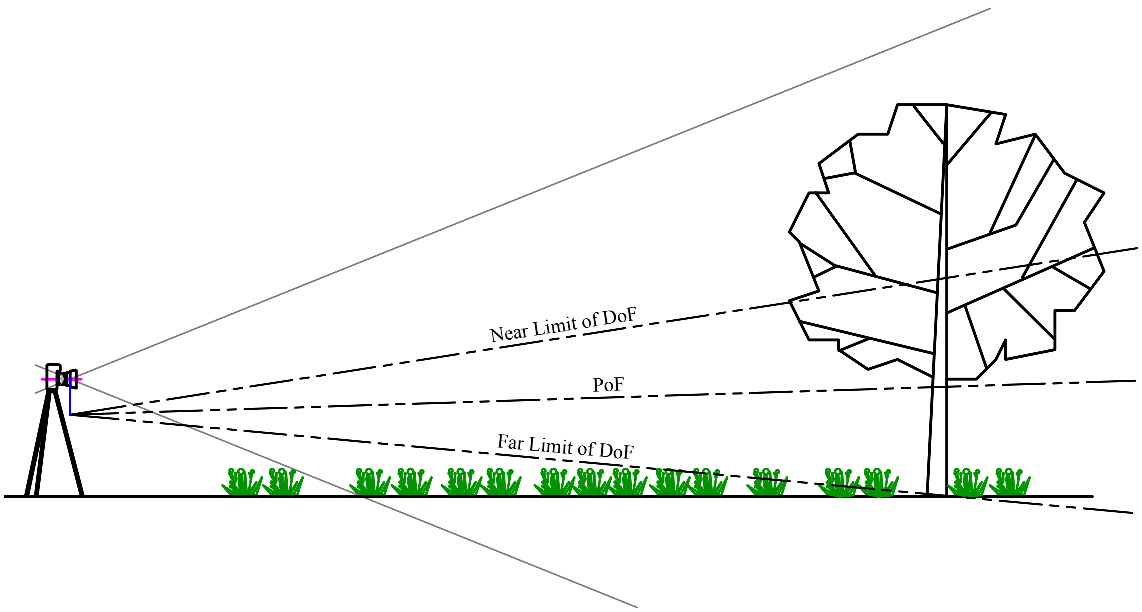

Figure 10. DoF with 8° Tilt at *f*/22, Far Focus

When nothing else seems to work, it may be tempting, especially for those new to camera movements, to set maximum tilt in attempt to sort things out. But in most cases, this only makes things worse. Figure 10 shows the DoF with the maximum tilt of 8°; at the minimum aperture of *f*/22, the apex of the DoF wedge is barely a foot below the camera, and the DoF is only between the middle and bottom of the tree. With maximum tilt, it is not possible to have the near flowers sharp at any focus setting.

Setting a large tilt gives a small angular DoF and places the apex of the DoF wedge very close to the camera; the combination usually isn't a good fit to a scene unless the camera is very close to the ground. A little tilt goes a long way, and setting too much tilt is a common error for photographers new to using camera movements.

As this example illustrates, the optimal tilt can be quite small, especially as the element with height moves closer to the camera; in some cases, the best results are obtained without using any tilt. Luong (2000) considers a situation with a large rock in the foreground, and discusses two methods for determining the best position for the PoF. Merklinger (1996, 113–122) analyzes a situation with even more constraints, yet determines that using tilt still may provide a slight advantage.

When there is substantial height very near the camera (e.g., a hallway in which the walls must be sharp), the region of interest isn't wedge-shaped, and it may not be possible get everything acceptably sharp. In such cases, setting the tilt to zero usually gives the best results.

In many cases, the benefits of using tilt are readily apparent. In the scene suggested by Figure 5, the near-to-far distance is considerable, and the required angular DoF is fairly small; the tilt can be set without great attention to detail and still give good results. In other cases, such as the scene suggested by Figures 6–11, the position of the PoF must be carefully chosen if tilt is to provide any benefit. And sometimes tilt will provide no benefit. In a situation such as the hallway just described, it's usually obvious that tilt will not help. But sometimes the only way to find out is to determine the required *f*-numbers with and without tilt.

The previous examples have involved rotating the top of the PoF forward so that the rotation axis is below the camera. This is by far the most common application, but it is also possible to rotate the PoF backward so that the rotation axis is above the camera; this can be useful when an overhead object such as a ceiling must be sharp.

Swing

The examples discussed have involved rotating the PoF about a horizontal axis, as often is employed with landscapes in which the height of the region of interest increases with distance. In some cases, the width of the region of interest increases with distance, and sharpness is best achieved by rotating the PoF about a vertical axis. With a most tilt/shift lense, swing is accomplished by rotating the front part of the lens until the rotation axis is vertical. Essentially the same techniques discussed for tilt apply equally well to swing.

Combined Tilt and Swing

In some cases, the subject plane is neither horizontal nor vertical, but somewhere in between. An example might be a field of flowers on a hill that slopes across the field of view. In such a case, sharpness is best achieved by employing both tilt and swing. On a view camera, these are separate movements; on most tilt/shift lenses, the combination is used by rotating the front of the lens until the axis of rotation is approximately parallel to the subject plane. The same procedures previously discussed apply.

Tilt and Swing in Close-up Photography

For a given tilt or swing, the angle of the PoF with the image plane is determined by changing focus. At close focus, however, rotation of the PoF is limited. Eq. (2) can be stated in terms of magnification m as

$$\tan\psi = \frac{m+1}{m}\tan\theta\,. \tag{3}$$

For example, the Canon TS-E 90 mm *f*/2.8 lens provides maximum magnification of 0.29; at maximum magnification and the maximum tilt of 8°, the angle of the PoF with the image plane is only about 32°. As with all close-up photography, the DoF is also limited, and the angular DoF is so small that the wedge shape usually affords little advantage. The chess board previously mentioned provides a good example: at close focus, it’s nearly impossible to have the line of sight parallel to the board and have both the near edge of the board and pieces on opposite side within the DoF—the line of sight must be at an angle to the board to get everything sharp. Nonetheless, tilt or shift can be very useful for closeups in which an essentially flat subject (e.g., a butterfly wing) cannot be kept quite parallel to the image plane.

Selective Focus: “Anti-Scheimpflug”

Although tilt and swing are usually used to get the greatest part of a scene acceptably sharp, the opposite effect is also possible. By using a small *f*-number and adjusting tilt or swing so that the plane of focus is as far away from most of the scene as possible, the part of the scene that is within the DoF can be minimized. Again using the chess board as an example, the plane of focus could be oriented away from the plane of the board, perhaps emphasizing the top of a single piece. Swing could be used to emphasize two pieces that lie on the PoF, leaving any other pieces out of focus.

In an outdoor scene, the PoF could be oriented to align with a picket fence crossing at an angle; with a large *f*-number, it might be possible to have most of the scene sharp, but with a small *f*-number, sharpness could be limited to the fence itself. Alternatively, by swinging the lens in the opposite direction, the PoF could be oriented so that it crossed the fence at an angle, placing only a short length of the fence within the DoF. Tilt and swing can also be used to provide selective focus of objects that are all at essentially the same distance from the camera. For example, with a swung lens, changing focus causes the region of sharpness to move across a row of buildings that are perpendicular to the line of sight.

Shift

Rising/Falling Front

When the image plane is parallel to the subject, all points in the subject are the same distance from the camera, and have the same magnification in the image. Consequently, parallel lines in the subject remain parallel in the image.[4] When the image plane is not parallel to the subject, some parts of the subject are at greater distances from the camera than others, and are recorded at lesser magnification, so parallel lines in the subject converge in the image.

For example, if the camera is pointed up to include the top of a tall building, vertical lines in the building converge, making the top of the building appear small, and in some cases causing the building to appear as if it were falling over backward.

This convergence of parallel lines can often be avoided with a tilt/shift lens by keeping the camera back vertical and moving the lens up. With rising front, the line of sight ("LoS") and image framing change but linear perspective does not.

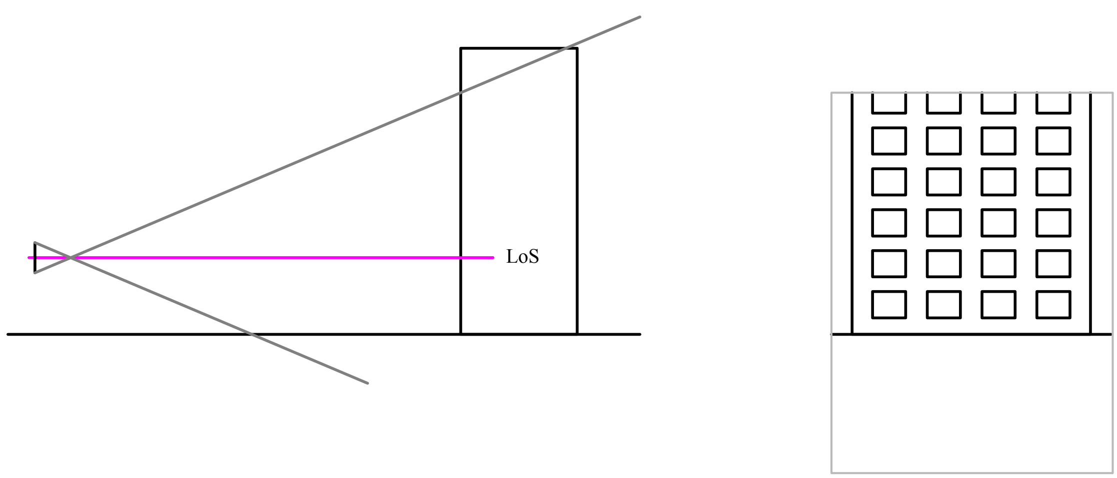

Figure 11. Building, with Camera Level

[4] Strictly, this is true only for a symmetrical lens. Because wide-angle lenses for reflex cameras are nearly always retrofocus designs, employing tilt or swing with a tilt/shift lens results in some convergence or divergence of parallel lines in a subject parallel to the image plane. When this happens, the angle of the camera must be adjusted until the lines are again parallel.

Consider a tall building, as suggested in Figure 11. With the camera level, the front of the building is parallel to the image plane, so the vertical lines of the building front remain vertical. But the top of the building isn't within the image, and the bottom of the image includes more of the foreground than is wanted, as shown on the right.

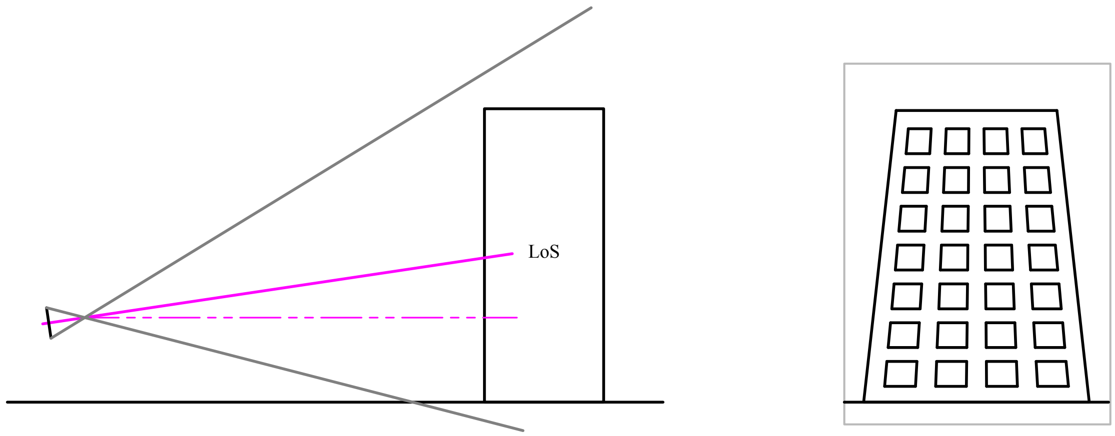

Figure 12. Building, with Camera Tilted up

If the camera is pointed up, as shown in Figure 12, the top of the building is now included, and much of the unwanted foreground is excluded. But the image plane is no longer parallel to the front of the building, so that the top of the building is farther from the image plane than the bottom of the building. Vertical lines converge, and the entire building front is no longer in exact focus.

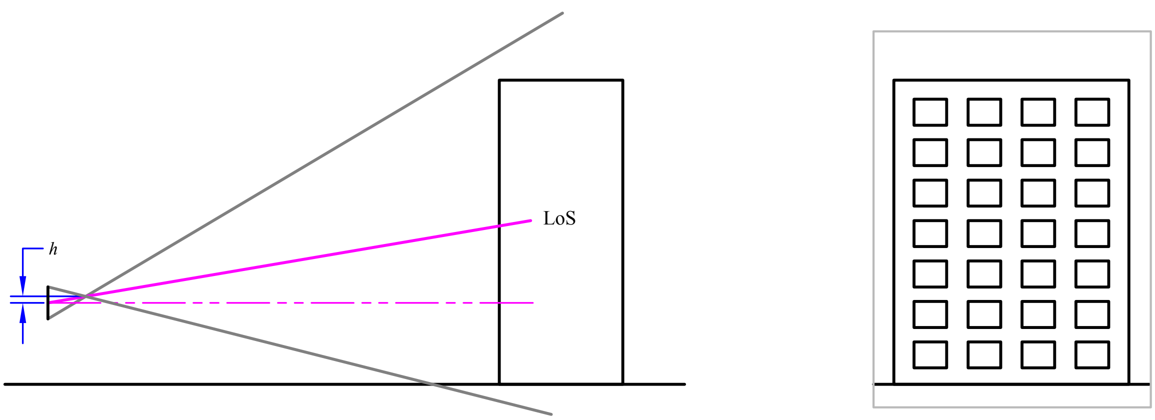

Figure 13. Building, with Camera Using Front Rise

In Figure 13, the image plane is kept parallel to the front of the building, and the lens is raised by a distance *h* to include the top of the building and exclude most of the foreground. Vertical lines remain parallel, and the entire building front remains in focus.

Falling front can be used to avoid convergence when placing a building at the top of an image to emphasize the foreground. Falling front is also useful when looking down from a high vantage point, such as from a trail above a stream in a forest; use of falling front there avoids divergence of the tops of the trees.

Rising or falling front may be useful even on a subject with no apparent straight lines if the shape of the subject is very familiar, such as with El Capitan in California's Yosemite Valley. When photographed by pointing an ordinary wide-angle lens up, such objects often have the appearance of falling over backward. Employing rising front with a 24 mm tilt/shift lens maintains the appearance with which viewers of innumerable published photographs are familiar.

Some objects may be too tall to photograph without pointing the camera up slightly, even with maximum shift. In some cases, completely avoiding convergence may look unnatural, and allowing slight convergence may be preferable. A common guideline is that when the line of sight to the top (or bottom) of an object is greater than 20 degrees, allowing some convergence usually gives a more pleasing result. The amount of convergence to allow is usually a matter of personal taste, and may vary from subject to subject.

An alternative may be to take the picture from an elevated floor of a nearby building, and using rising front to adjust the framing. The resulting image will not be quite the same as one taken from ground level, but the overall effect may be more pleasing. If a nearby building is not available, a ladder can sometimes be used to raise the camera position.

In some cases, it may be desirable to increase convergence of vertical lines. For a tall building, this can be done by using falling front and pointing the camera up.

Lateral Shift

If a building is photographed from an oblique camera position, the camera back can be kept parallel to one wall and lateral shift used to prevent convergence of horizontal lines in that wall. If the building is tall, a combination of shift and rising front may be needed to prevent convergence of vertical lines; this is accomplished by rotating the shift function and adjusting the shift until the desired result is obtained. In some cases, it may not be possible to completely avoid convergence in both vertical and horizontal lines.

When photographing a highly reflective object, such as a mirror, that is directly in front of the camera, the camera will appear in the image. This can be avoided by moving the camera to one side and shifting the lens laterally until the image framing is the same as for the direct position. The relationship of foreground objects will not be the same as for the direct framing, but convergence of horizontal lines will be avoided.

Sometimes it is desirable to eliminate a foreground object from a picture; in some cases this can be accomplished by moving the camera to the side away from the unwanted object, and shifting the lens in the opposite direction until the framing is the same as it was before moving the camera. As with the reflective object, the relationship of other foreground objects to the background will change, but convergence of horizontal lines will be avoided.

Panorama

A panoramic image can be created by fully shifting the lens to one side, taking a picture, fully shifting the lens to the opposite side, and taking a second picture. The resulting images can be combined to form a single image; with a full-frame 35 mm camera, the effect is equivalent to a 24 mm × 58 mm format with the original Canon TS-E lenses, and slightly wider with the newer Canon and Nikon tilt/shift lenses.

Combined Rise and Lateral Shift

When photographing the front of a building, it's often desirable to include part of the side of the building, while avoiding convergence of vertical or horizontal lines. This can be accomplished by a combination of rising front and lateral shift; with most tilt/shift lenses, this is done by revolving the lens about its axis before shifting. Several attempts may be needed to get the best combination of rise and shift, and the amount of shift may not allow complete elimination of both vertical and horizontal convergence. When the original Canon TS-E 24 mm lens is revolved with maximum shift, vignetting may be possible on full-frame 35 mm, so the viewfinder or LCD should be carefully examined. The TS-E 24 mm II lens and the Nikon PC-E 24 mm lens have larger image circles, so there is little mechanical vignetting.

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Further Reading

Nearly everything written on camera movements is intended for view camera users; however, subject to a few adaptations, much of the technique also applies to tilt/shift lenses.

Books

Eastman Kodak Company. *Kodak Guide to Large Format Photography*. Rev. ed. Rochester: Silver Pixel Press, 1998. Kodak publication number O-18e. ISBN 0-87985-771-4

Shaman, Harvey. *The View Camera*. Rev. ed. New York: Amphoto, 1991. ISBN 0817463755 (pbk.)

Simmons, Steve. *Using the View Camera*. New York: Amphoto, 1987. ISBN 081746347X

Stone, Jim. *A User's Guide to the View Camera*. 3rd ed. Upper Saddle River, NJ: Pearson/Prentice Hall, 2004. ISBN: 0130981168

Stroebel, Leslie D. *View Camera Technique*. 7th ed. Boston: Focal Press, 1999. ISBN 0240803450 (alk. paper)

Papers

Wheeler, Robert. 2003. Notes on View Camera Geometry (PDF). Includes the derivations of most formulas.

Web Resources

- The Large Format Page: www.largeformatphotography.info/
- Harold M. Merklinger's Photo Books: www.trenholm.org/hmmerk/
- Robert Wheeler's Photo Site: www.bobwheeler.com/photo/

Appendix
DoF Formulas for a Tilted Lens

For given near and far angular DoF limits ψ_n and ψ_f, the optimal angle for the PoF is given by

$$\tan\psi = \frac{2\tan\psi_n \tan\psi_f}{\tan\psi_n + \tan\psi_f}. \tag{A1}$$

The required *f*-number is given by

$$N = \frac{f}{c}\frac{\tan\theta\left(\tan\psi_f - \tan\psi_n\right)}{2\tan\psi_f \tan\psi_n - \tan\theta\left(\tan\psi_f + \tan\psi_n\right)}, \tag{A2}$$

where c is the acceptable circle of confusion. When the angle of the PoF with the image plane is large in comparison with the lens tilt, this simplifies to

$$N \approx \frac{f}{c}\frac{\tan\theta\left(\tan\psi_f - \tan\psi_n\right)}{2\tan\psi_f \tan\psi_n}. \tag{A3}$$

As might be expected, the *f*-number increases with increasing angular DoF; however, it also increases with increasing tilt, and decreases with increasing angle of the PoF with the image plane, so the combined effect is usually not easy to estimate.

Formulas on the image side of the lens are much simpler than the object-side formulas given above. To a good approximation, the required *f*-number is directly proportional to the *focus spread*, the difference between the image distances corresponding to the near and far limits of DoF:

$$N \approx \frac{1}{m+1}\frac{v_n - v_f}{2c}, \tag{A4}$$

where v_n and v_f are the near and far image distances. When the magnification is small, this simplifies to

$$N \approx \frac{v_n - v_f}{2c}. \tag{A5}$$

On most helicoid-focused lenses, direct measurement of focus spread is difficult, but the focus spread is proportional to the rotation of the focusing ring. Most lens DoF scales are based on Eq. (A5); they are fine when the subject distance is large in comparison with the lens focal length, but for close-up work they require a correction for magnification. For example, at 0.25 magnification, the *f*-number determined using Eq. (A5) would be divided by 1.25, corresponding to about a ⅔-step reduction.

The formulas are useful in determining the focus and *f*-number from a diagram, but in the field, it's usually easier to get these settings visually, as is discussed in the section Determining Focus and *f*-number.