Location of Base for Seismic Design

By Dominic J. Kelly, P.E.

In the *Minimum Design Loads for Buildings and Other Structures* (ASCE/SEI 7-05) reference standard, published by the Structural Engineering Institute of the American Society of Civil Engineers, base for seismic design is defined as "the level at which the horizontal seismic ground motions are considered to be imparted to the structure". This definition of "base" is sometimes misunderstood or misinterpreted by engineers. Engineers often question where the base is for a building when site conditions are not straight forward, for example for buildings located on a sloping site or for a building on piles. This article provides guidance to engineers as to how to locate the base for seismic design.

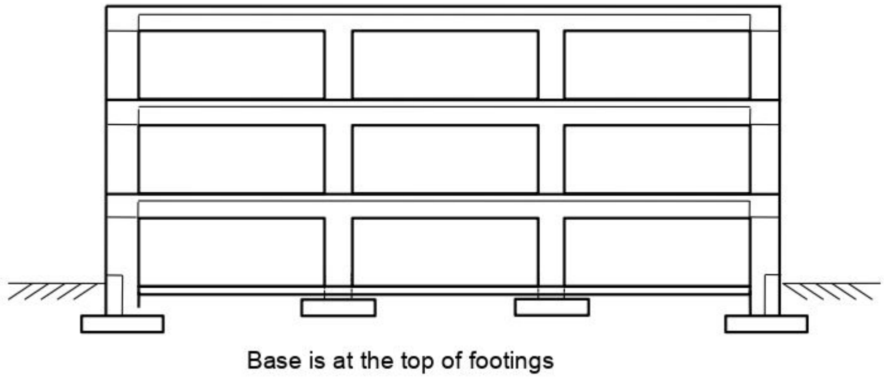

Figure 1: Base for a level site.

Factors Affecting the Location of Base

The definition of "base" is intentionally broad, as many factors affect its location. Some of the factors are:

- Location of the grade relative to floor levels;
- Soil conditions adjacent to the building;
- Openings in basement walls;
- Location and stiffness of vertical elements of the seismic-force-resisting system;
- Location and extent of seismic separations;
- Depth of basement;
- Manner in which basement walls are supported;
- Proximity to adjacent buildings; and
- Slope of grade.

Note that piles are not included in this list. Horizontal ground motion is of primary importance for locating the base. In general, horizontal ground motion is imparted to the structure through bearing and friction on the sides of basement walls and foundation elements, and through friction on the underside of slabs and shallow foundation elements. Piles, both vertical and battered, generally move laterally with the horizontal ground motions and have little to no impact on the level at which horizontal seismic ground motions are imparted to a building.

Buildings on Level Sites

Buildings without Basements on Level Sites

For typical buildings on level sites with competent soils, the base is generally close to grade. For a building without a basement, the base is generally established near the ground-level slab elevation (*Figure 1*). Where the vertical elements of the seismic-force-resisting system are supported on interior footings or pile caps, the base is commonly established at the top of these elements or else at the top of the slab-on-grade. Where the vertical elements of the seismic-force-resisting system are supported on top of perimeter foundation walls, the base is typically established at the top of the foundation walls. Often vertical elements are supported at various elevations on the top of footings, pile caps, or perimeter foundation walls. Where this occurs, an engineer must use his or her judgment to locate the base. The base can usually be conservatively established as the lowest elevation of the tops of elements supporting the vertical elements of the seismic-force-resisting system.

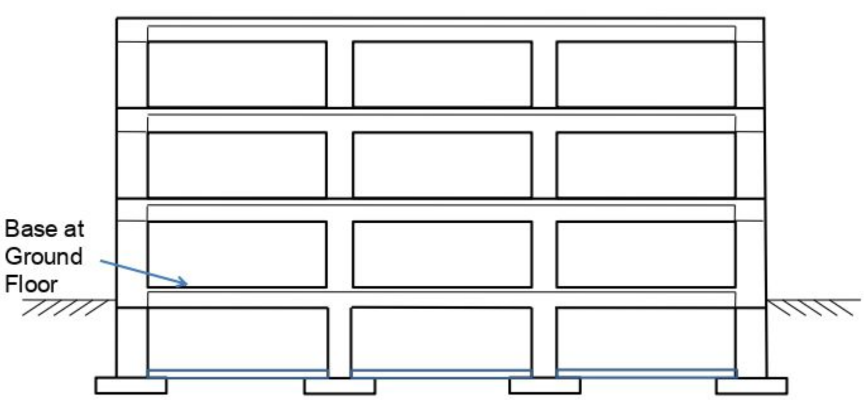

Figure 2: Base at ground floor level.

Buildings with Basements on Level Sites

For a building with a basement located on a level site, it is often appropriate to locate the base at the floor closest to grade (*Figure 2*). For the base to be near grade, stiff soils are required over the depth of the basement because seismic forces will be transmitted to and from the building over the height of the basement walls. For tall or heavy buildings or where soft soils are present near the surface, the soils may compress too much laterally during an earthquake to transmit seismic forces near grade. The engineer of record is responsible for making a determination as to whether the soils are stiff enough to transfer the seismic force at a level close to grade. If the base is to be established at the level located closest to grade, the profile over the depth of the basement should not include soils that are liquefiable, quick or highly sensitive clays, or soils that are weakly cemented that are susceptible to failure or collapse in a maximum considered earthquake. If these soils are present over the depth of the basement, the base should be established at the bottom of the basement.

Occasionally, the base may be at the floor level adjacent to, or as much as a few feet above, grade. For the base to be located at

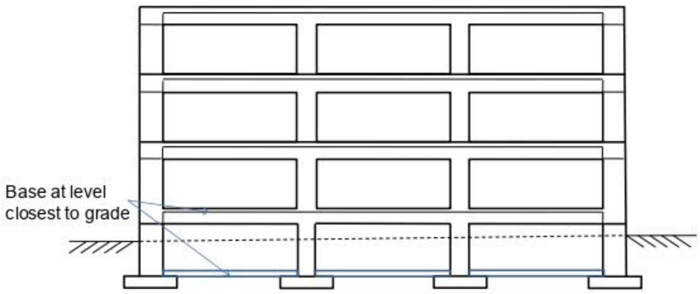

Figure 3: Base at level closest to grade elevation.

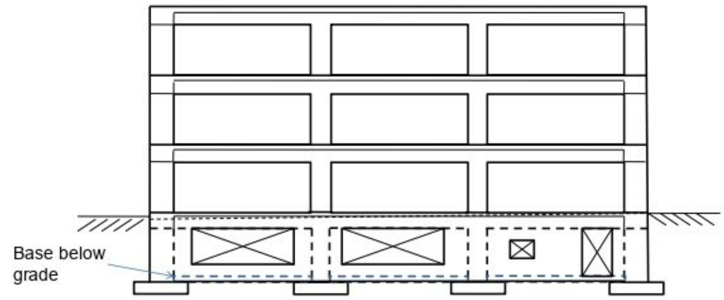

Figure 4: Base below substantial openings in basement wall.

a floor level above grade, stiff foundation walls on or near all sides of the building should extend to the underside of the elevated level that is to be considered the base. The validity of having the base above grade is based on the same principles used to justify the two-stage equivalent lateral force procedure permitted in Section 12.2.3.1 of ASCE/SEI 7-05. This procedure allows one to apply the equivalent lateral force procedure to a flexible upper portion of a building as if it were founded at the ground level instead of on top of a lower portion of the building that is 10 times as stiff as the upper portion. For a floor level above grade to be considered the base, grade should generally not be lower than one-half the height of the basement story below the level considered base (*Figure 3*). The concept of establishing the base at a level above grade is also applicable to small structures. Typical examples include light-framed structures that rest on a stiff basement or crawl space walls of concrete or masonry. The two-stage analysis procedure can be used to design the basement or crawl space walls with the weight of the first level included, but the design of the upper stories would not be affected by the mass of the concrete or masonry walls or the level of frame supported on the top of these walls.

If the base is located at the level closest to grade, the lateral stiffness of the basement walls should be substantially greater than the stiffness of the vertical elements of the seismic force-resisting system. However, a condition where the basement walls extend to slightly above grade on a level site and may not provide adequate stiffness is where the basement walls have many openings for items such as light-wells, areaways, windows, and doors (*Figure 4*). Where the stiffness of the basement walls is not much greater than the vertical elements of the seismic-force-resisting system above grade, consideration should be given to establishing the base at the basement slab or basement foundation elements. If all of the vertical elements of the seismic-force-resisting system are located on top of basement walls and there are many openings in the basement walls, it may be appropriate to establish the base at the bottom of the openings. Another condition where the basement walls may not be stiff relative to the structure above grade is where the vertical elements of the seismic force-resisting system are long concrete shear walls extending over the full height and length of the building (*Figure 5, page 10*). For this case, the appropriate location for the base is likely at the foundation level of the basement walls, unless the soils against the basement walls are very stiff.

Where the base is established below grade, the weight of the portion of the story that is partially above and below grade must be included as part of the effective seismic weight. If the equivalent lateral force procedure is used, this can result in disproportionately high forces in upper levels due to a large mass at this lowest level above the base. The magnitude of these forces can often be mitigated by using the two-stage equivalent lateral force procedure where allowed, or by using a dynamic analysis to determine force distribution over the height of the building. If a dynamic analysis is used, it may be necessary to include many modes to capture the required mass participation unless soil springs are incorporated into the model. Incorporation of soil springs into the model will also minimize seismic forces in the upper levels.

Other Conditions Requiring the Base to Be Below Grade

Other conditions may also necessitate establishing the base below grade for a building with a basement that is located on a level site. Such conditions include: where seismic separations extend through the floor structures located close to and above grade; where the floor diaphragms close to and below grade are not tied to the foundation wall; where the floor diaphragms, including the diaphragm for the floor close to grade, are flexible; and, where other buildings are located nearby. Knowledge of dynamic response of buildings and engineering judgment are often critical in defining the base of these structures.

Effect of Seismic Separations

For a building with seismic separations extending through the height of the building including levels close to and below grade, the separate structures will not be supported by the soil against a basement wall on all sides in all directions. If there is only one joint through the building, assigning the base to the level close to grade may still be appropriate if the soils over the depth of the basement walls are

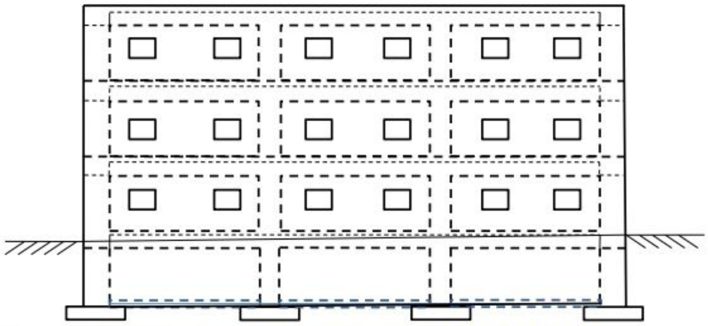

Figure 5: Base at foundation level where concrete shear walls extend over the full height and length of the building.

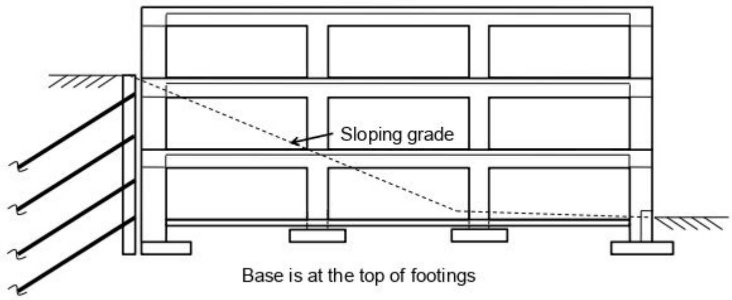

Figure 6: Building with tie-back or cantilevered retaining wall that is separate from the building.

stiff and the diaphragm is rigid. Stiff soils are required so that the seismic forces can be transferred between the soils and basement walls in both bearing and side friction. The structural engineer generally consults with a geotechnical engineer to determine if the soils are stiff enough. If the soils are not stiff, adequate side friction may not develop for movement in the direction perpendicular to the joint and, consequently, the base should be located at the level of the basement slab or foundations.

For large footprint buildings, seismic separation joints may extend through the building in two directions and there may be multiple parallel joints in a given direction. For individual structures within these buildings, substantial differences in the location of the center of rigidity for the levels below grade relative to levels above grade can lead to torsional response. For such buildings, the base should usually be at the foundation elements below the basement or, in the case where the joints are not present in the lower basement levels, the base may be at a basement slab level where the separations are not provided.

Floors Separated from Basement Walls

Where basement floor levels are not tied to foundation walls, the base may need to be located well below grade at the foundation level. An example is a building with tie-back walls and post-tensioned floor slabs. For such a structure, the slabs may intentionally not be tied to the wall to allow relative movement between them. In other cases, a soft joint may be provided. If shear forces cannot be transferred between the wall and a ground-level or basement floor, the location of the base will depend on whether forces can be transferred through bearing between the floor diaphragm and the basement wall, and between the basement wall and the surrounding soils. Floor diaphragms bearing against the basement walls must resist the compressive stress from earthquake forces without buckling. If a seismic or expansion joint is provided in one of these buildings, the base will almost certainly need to be located at the foundation level or a level below grade where the joint no longer exists.

Flexible Diaphragms near Grade

If the diaphragm at grade is flexible and does not have substantial compressive strength, the base of the building may need to be located below grade. This condition is more common with existing buildings. Newer buildings with flexible diaphragms should be designed for compression within elements of the diaphragm to avoid the damage that would occur otherwise.

Nearby Buildings

The proximity to other buildings can also impact the location of the base. If other buildings with basements are located adjacent to one or more sides of a building, it may be appropriate to locate the base at the bottom of the basement. The interaction of the structure, the surrounding soils, and adjacent buildings, and analyses that account for such interaction, are complex. Well established rules of thumb about when to consider interaction of adjacent structures through the soils are not available for commercial buildings. Although not well established within commercial building design, a rule of thumb for when interaction occurs is when the buildings are closer to one another by an amount that is less than two times the depth of the basements; however, this rule is not always applicable and other factors such as the mass and plan dimensions of the structures can be equally as important. In general, the closer buildings are to one another, the more likely it is that the base should be below grade.

Buildings on Sloping Sites

For buildings on sites with sloping grade, many of the same considerations for a level site are applicable. For example, on steeply sloped sites, the earth may be retained by a tie-back wall so that the seismic-force-resisting system of the building does not have to resist the lateral soil pressures. For such a case, the building will be independent of the wall, so the base should be located at a level close

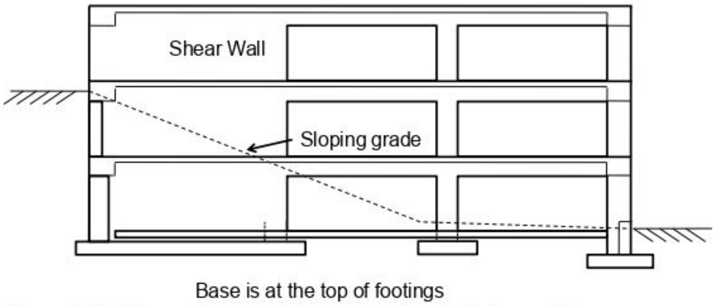

Figure 7: Building with vertical elements of the seismic force-resisting system supporting lateral earth pressures.

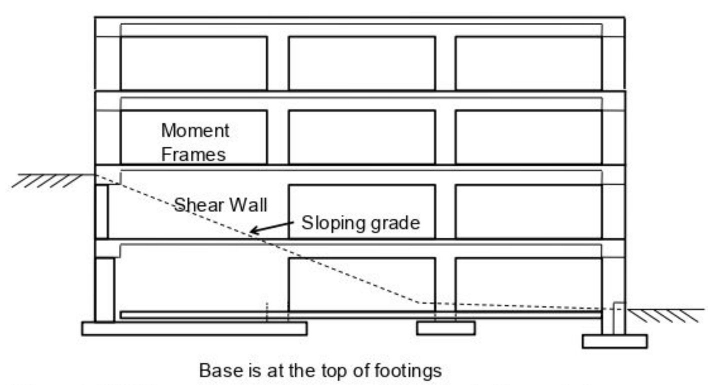

Figure 8: Building with vertical elements of the seismic force-resisting system supporting lateral earth pressures.

to the elevation of grade on the side of the building where it is lowest (*Figure 6*). Where a building's vertical elements of its seismic-force-resisting system also resist lateral soil pressures (*Figure 7*), the base should also be located at a level close to the elevation of grade on the side of the building where grade is low. For these buildings, the seismic-force-resisting system below highest grade is often much stiffer than the system used above it (*Figure 8*), and the seismic weights for levels close to and below highest grade are greater than for levels above highest grade. Use of a two-stage equivalent lateral force procedure can be useful to minimize design forces in the upper levels of these buildings. If the equivalent lateral force procedure is used without doing the two-stage procedure, lateral forces in the upper more flexible portion of the building will be greater, as the mass of the heavy lower portion is included in the base shear that must be distributed over the height of the building.

Where the site is moderately sloped so that it does not vary in height by more than a story, stiff walls often extend to the underside of the level close to the elevation of high grade, and the seismic-force-resisting system above grade is much more flexible than it is below grade. If the stiff walls extend to the underside of the level close to high grade on all sides of the building, locating the base at the level closest to high grade may be appropriate. If the stiff lower walls do not extend to the underside of the level located closest to high grade on or near all sides of the building, the base should be assigned to the level closest to low grade. If there is doubt as to where to locate the base, it should conservatively be taken at the lower elevation.

Summary

The decision as to where to locate the seismic base is not always straight forward. In general, the base of the structure should be located where seismic forces enter and exit the building. Designers generally locate the base at the level closest to the grade. If there is doubt as to where to locate the base, it should generally be taken at the lower elevation.

The Seismic Code Committee of ASCE 7 recently considered changes to its requirements that would establish the location of the seismic base. Discussions of the committee led to the realizations that numerous parameters influence the location of seismic base, and that creating comprehensive provisions adequately establishing the seismic base was unrealistic. Language similar to that which appears in this article is being considered for incorporation into the commentary to SEI/ASCE 7-10.▪

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