Heavily Loaded Strap Footings

Design, Detailing and Behavior

By Truly Guzman, P.E. M.Sc

In dense urban environments where every inch of construction is precious and needs to be maximized, it is usual for footings or pile caps supporting exterior columns to be moved inside property lines. This in turn creates an eccentric load on these elements. In the city of New York, especially in the borough of Manhattan, where high capacity bedrock can be found at reasonably shallow depths, it is common to support tall buildings on isolated footings bearing on rock. Strap footings are usually the most efficient mechanism to remove eccentricity from exterior footings and to accomplish a more uniform distribution of bearing pressure.

A strap footing consists of two spread footings linked together by a strap beam. Its design is based on the assumption that this beam is not in contact with the bearing stratum such that no soil pressure is exerted on the beam itself. The means used to provide this pressure-relieving mechanism varies; some engineers indicate polystyrene between the beam and the bearing soil, others prefer simply to show a gap, and still others prescribe a tapered beam. Most of the time, verifying that this requirement has been satisfied during construction is not considered crucial. Moreover, in many cases the responsibility for inspecting and controlling this detail is not clear or can easily be neglected. The question arises: How important is it to relieve this pressure from the strap beam in order for it to behave as designed? In other words, can this pressure be neglected for all practical purposes?

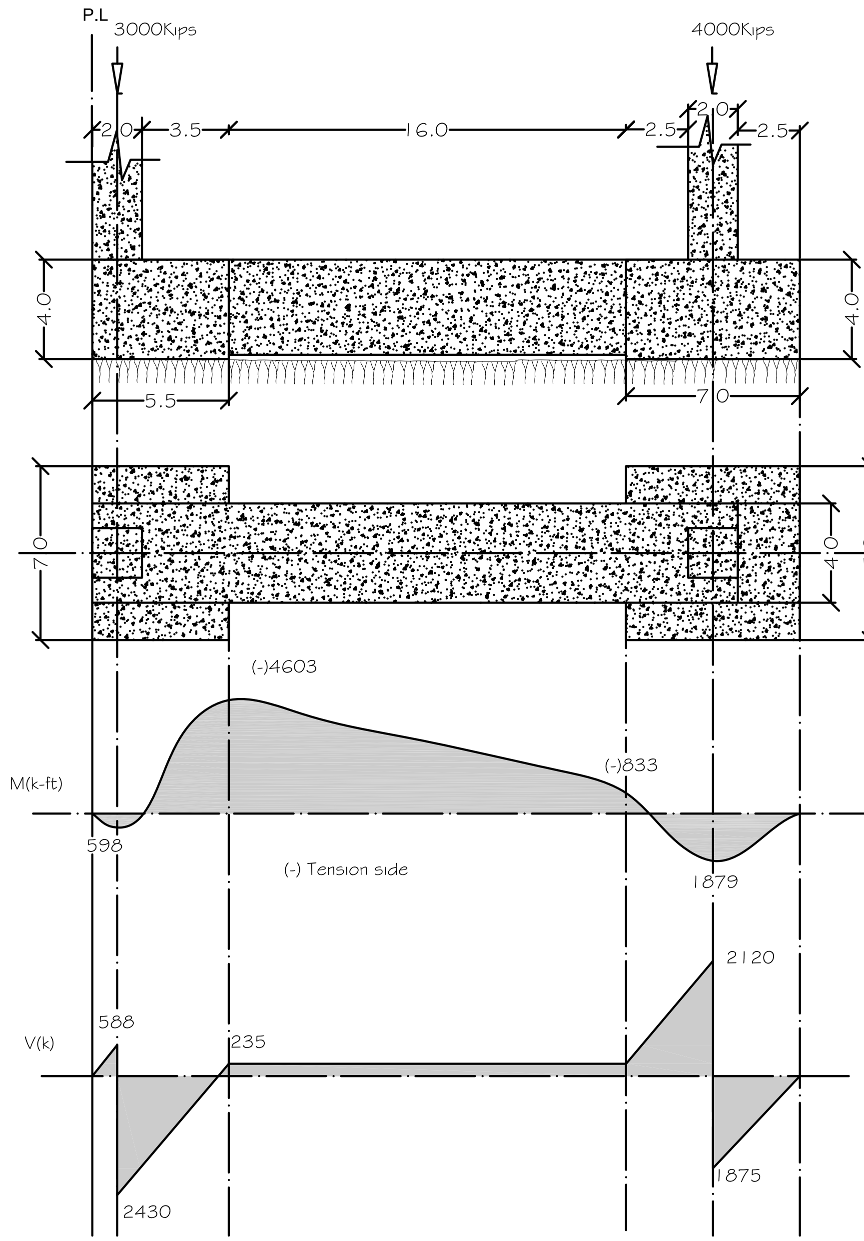

Figure 1: Moment and Shear Diagrams on a Strap Footing.

Case Study

An example is shown in *Figure 1*, where a strap footing was designed to support a 27-story building bearing on rock with a bearing capacity of 25 tons per square foot.

By performing a simple conventional rigid static analysis and assuming that the strap beam is not in contact with the rock, the resulting design moment and shear for the beam are 4,600 kips-feet and 235 kips respectively. A 6-foot-deep, 4-foot-wide beam is chosen as the design section. In most cases, the depth of the strap beam is controlled either by the depth of footing required to avoid punching shear failure or by the maximum amount of flexural reinforcement allowed. Typically, minimum or no shear reinforcement is required.

If the beam is constructed by placing concrete directly against the rock, it is apparent that the pressure imposed on the beam will be a direct function of the width of the beam. In theory, if the beam is of infinitesimally small width but has a comparable bending stiffness to the original beam, the results should be similar. In order to determine the stage at which the resulting moments and shears become similar, with and without bearing pressure exerted on the beam, the author carried out a series of numerical analyses. The model had compression-only spring elements with a subgrade reaction modulus of 800 pounds per cubic inch to represent the rock under the footings, and two-thirds of this value for the rock under the grade beam in order to account for shape effects.

Since no tension was allowed on the springs, the strap beam was able to "relax"

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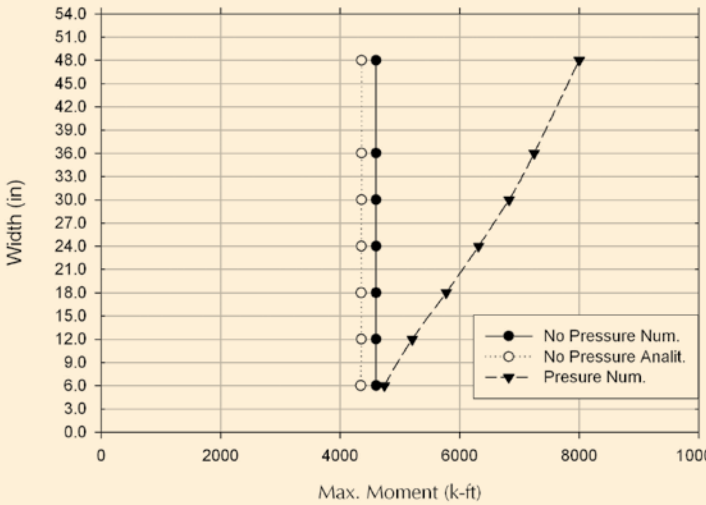

Figure 2a: Variation in Moments (kips-ft).

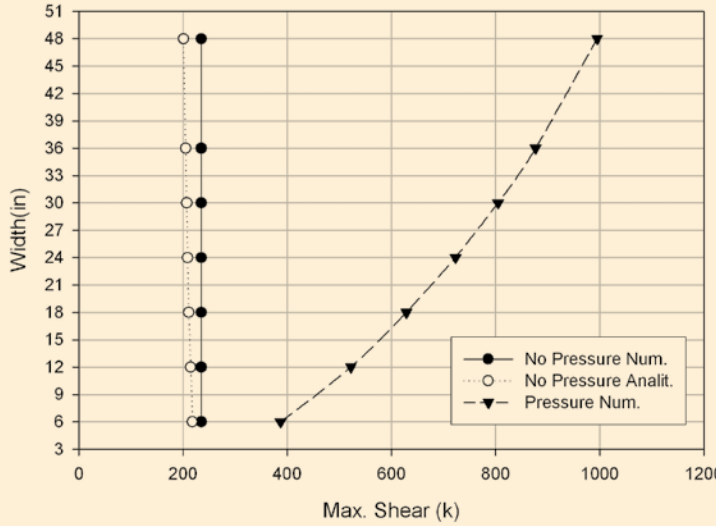

Figure 2b: Variation in Shear (kips).

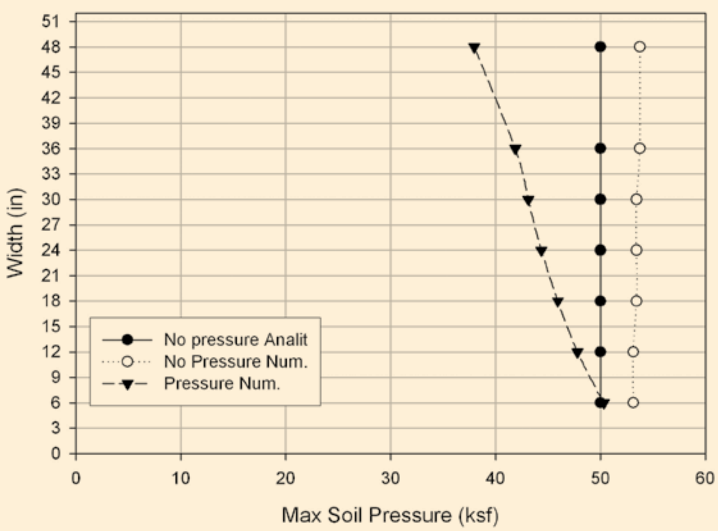

Figure 2c: Variation in Soil Pressure (kips per square foot).

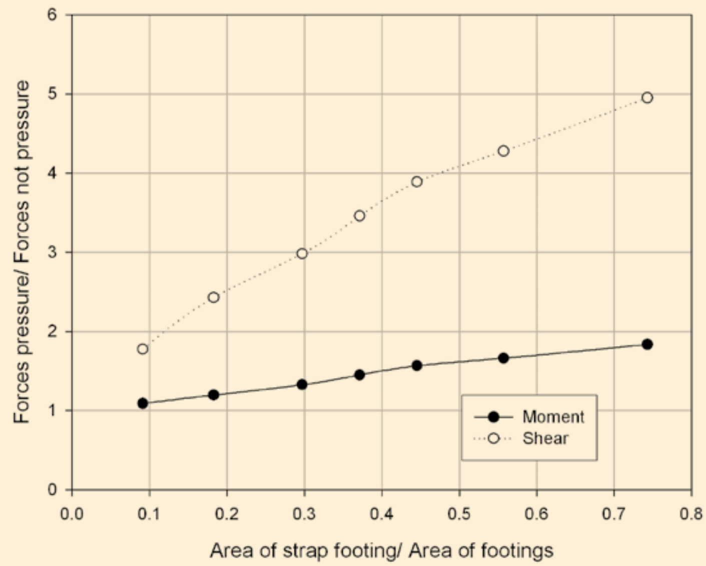

Figure 3: Area of Footings vs. Area of Strap Beam.

in the areas with less pressure and even lose contact with the rock where required – a more realistic condition than the simple rigid analysis could simulate. The width of the beam varied from the original 48 inches down to 6 inches, with 5 intermediate widths, while keeping the moment of inertia constant. In addition, a numerical analysis assuming no pressure on the beam, with the same variations in width, served as a basis for comparison with the original analytical results.

The increments on moment and shear at the critical section as a function of beam width are plotted in *Figures 2a, 2b* and *2c*.

It is clear from the results that when no pressure is allowed, the moments and shears stay constant as the width changes. On the other hand, when pressure is allowed, the moments and shears increase considerably with width. For the original 48-inch-wide beam, an increase of about 73% in moment and about 400% in shear can be observed. As expected, when the width of the beam is the smallest, the difference between the no-pressure and with-pressure analyses is small, as well. Nevertheless, even for the 6-inch-wide beam, the difference in shear is still considerable at about 65%, while the difference in moment goes down to about 3% .

The variation exhibited in soil pressure is also expected – when the area in contact with the soil is considerable, the total load is distributed over a broader area, creating less overall soil pressure.

A small parametric study illustrates how the relationship between total area of footing and total area of strap beam affects the increase in forces on the beam. The variation shown in *Figure 3* can be interpreted as mostly linear.

Conclusion

Results indicate that when a strap footing is used as part of a foundation system, a detail that allows for pressure to be relieved from the strap footing is necessary on construction documents. Without it, a considerable unforeseen load path could be created that may result in the failure of the strap beam, followed by overstress of the soil/rock under the eccentric footing. It is also important to emphasize the need for field enforcement and control of these requirements.

The author recommends the two options shown in *Figure 4* in order to avoid field mistakes. It is also good to emphasize that if Option 1 is chosen, a low-density, low-modulus polystyrene must be specified. The thickness should be slightly greater than the maximum expected settlement of the footings. Furthermore, if the contractor prefers to perform a non-monolithic pour, construction joint keys must be oriented as indicated. Option 2 has the advantage of saving concrete, with the drawback of more labor-intensive formwork. Of course, there is always the alternative of explicitly accounting for the pressure on the beam at the design stage, rather than neglecting it. However, it is obvious from the results of this study that this can be an inefficient and uneconomical solution.▪

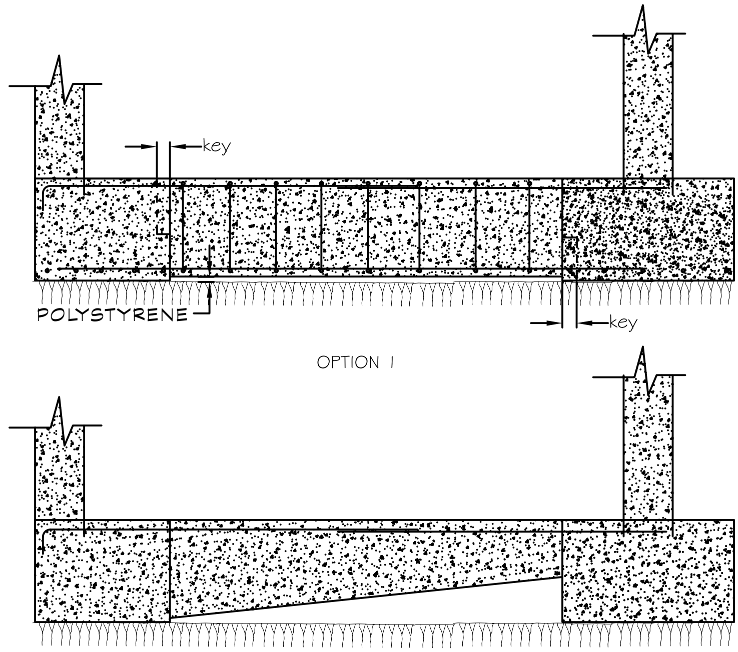

Figure 4: Suggested Construction Details.

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