# ACCIDENTAL ANALOG

## Abstract

A designer of a post-frame building must compute the deformations, internal forces and stresses of the post-frame members, diaphragms and shear walls. This analysis is based on the principle that stiffer elements will resist more of the load. The process begins with the development mathematical models which accurately reflect the performance of the structural element. These models are commonly called "analogs." This article reviews the practice of modeling a post embedded in soil as fixed at grade and then using the formulas in the International Building Code to check the embedment depth. It argues that this practice:

• violates the logical principle of contradiction;

• commits the logical fallacy of assuming what it is attempting to determine;

• is justified by neither expediency nor experience;

• introduces significant error into the analysis of the post-frame building.

## Review of the IBC Embedment Formulas

Section 1807.3 of the 2009 IBC covers embedded posts and poles. This section divides embedded posts into two conditions: non-constrained and constrained. A non-constrained post is one that has nothing to push against at grade and a constrained post does. In the normal post-frame building with a floor slab, the posts on the side the wind is blowing against can push against the floor slab so they are constrained. Unless the posts are somehow pinned to the slab, the posts on the opposite wall are non-constrained. Equation 18-1 provides a minimum embedment depth for a non-constrained post and Equations 18-2 and 18-3 provide the minimum embedment depth for constrained post.

Meador (1997) stated that these formulas were derived using the first three following assumptions. McGuire (1998) pointed out the fourth assumption.



The "accident" - the forces at grade for a simple cantilever are the same for a fixed base analog as for a post embedded in an elastic material. This led designers to rashly assume you could model an embedded post as fixed at the base.
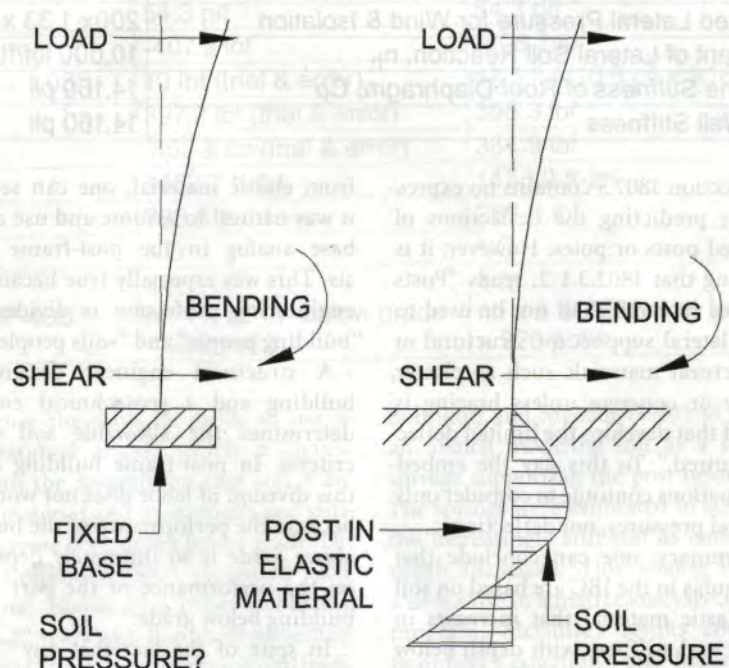
**FIGURE 1**
**NON-CONSTRAINED POSTS**

1. The soil resistance to deformation is proportional to displacement.

2. The resistance to deformation increases linearly with depth below grade.

3. The post is rigid below grade.

4. The shear force at grade acts to increase the effect of the moment at grade, not to decrease it.

In "Pole Building Design" by Donald Patterson, first published in 1957, Patterson describes the minimum embedment depth as "The depth of set required to prevent the rotation of a can-

tilever pole acted on by a lateral force" and the depth "required to prevent objectionable deflection of the pole axis from its original position." Patterson's illustrations DO NOT show a fixed base, rather they show a member cantilevering from a material as described in assumptions 1 through 3 above under a load described in assumption 4. See **Figure 1**. Although controlling deflections is his stated objective, he presents no method of estimating these deflections. He implies that members meeting the criteria he presents will have acceptable deflections.

Table 1: Building parameters & wind pressures

| Building Width x Length x Height, Roof Pitch | 40' x 80' x14', 4/12 |
|---|---|
| External Windward Wall Pressure | 10.61 psf |
| External Leeward Wall Pressure | -3.98 psf |
| Internal Pressure | +/- 2.81 psf |
| Net Wind Load on Roof | 60.17 plf |
| Post Spacing & Embedment | 8' oc, 48" Embedment |
| Post Description & Dressed Size | 3 ply 2x6 #1 SP w/glued finger joints, 4.31" x 5.31" |
| Post Modulus of Elasticity adjusted for Moisture | 1,700,000 psi x 0.9 = 1,530,000 psi |
| Effective width, Be | 0.63 ft |
| Grade Condition Windward | Constrained |
| Grade Condition Leeward | Non-constrained |
| Soil Type per ASABE EP-486.1 Table 1 | Type 4 Firm |
| Soil Lateral Pressure per unit Depth, S | 200 psf/ft |
| Adjusted Lateral Pressure for Wind & Isolation | 200x 1.33 x 2 = 532 psf/ft |
| Constant of Lateral Soil Reaction, $n_h$ | 10,000 lbf/ft^4 |
| In Plane Stiffness of Roof Diaphragm, Cp | 14,160 pli |
| End Wall Stiffness | 14,160 pli |

IBC Section 1807.3 contains no expressions for predicting the deflections of embedded posts or poles. However, it is interesting that 1802.3.1 2. reads "Posts embedded in earth shall not be used to provide lateral support for structural or nonstructural materials such as plaster, masonry or concrete unless bracing is provided that develops the limited deflection required." To this day the embedment equations continue to consider only forces and pressures, not deflections.

In summary, one can conclude that the formulas in the IBC are based on soil as an elastic material that increases in strength and stiffness with depth below grade but they give no guidance to determine deformations. Further, because they provide no method of calculating deformations, we can conclude that they were derived to apply in those situations where deformations do not have to be calculated in order to determine the distribution of forces within the structure. Examples of such structures are billboard signs and flag poles.

**Fixed Base Accident**

Lateral load is resisted in a post-frame building by the complex interaction of post-frames and diaphragms. To determine the forces resisted by each element, it is certainly necessary to calculate deflections. Because of the "accident" that the forces at grade are the same for a fixed base cantilever as for a cantilever

from elastic material, one can see how it was natural to assume and use a fixed base analog in the post-frame analysis. This was especially true because the engineering profession is divided into "building people" and "soils people."

A structural engineer designs the building and a geotechnical engineer determines the allowable soil design criteria. In post-frame building design this division of labor does not work well, because the performance of the building above grade is so intimately dependent on the performance of the part of the building below grade.

In spite of the fact that any "go-fer" on a building crew can tell you that a post-frame building is not the same as a billboard sign, most of the "building people" decided to assume that the posts are fixed at grade because it made their calculations easier and they didn't have to try and understand the complexities of soil modeled as an elastic material. It is the contention of this paper that this development was an "accident" of history and that designers fell into using it without seriously examining the implications of its use. They just assumed that because the fixed base analog gives the same forces as a cantilever from an elastic material it was adequate. The truth is that it leads to erroneous results when the designer needs to analyze a structure more complex than a bill board sign such as a post-frame building.

**Aristotle, Aquinas, etc.**

The principle of contradiction is the axiom or law of thought that a thing cannot be and not be at the same time, or a thing must either be or not be, or the same attribute cannot at the same time be affirmed and denied of the same subject. This principle is fundamental in both Western and Eastern philosophies (although still debated in quantum mechanics.) An example is that the statements "That cat is dead" and "That cat is alive" cannot both be true at the same time. That cat has to either be either dead or alive.

The first assumption in the derivation of the embedment formulas is that the soil's resistance to deformation is proportional to displacement. A fixed base analog is perfectly non-proportional. Regardless of the loads applied to it, deformation is always zero. Thus its resistance to deformation is infinite. It is a contradiction in the same analysis to assume that soil resistance to deformation is at the same time both proportional to displacement and infinite. It simply does not make sense.

The second logical error in using the fixed base analog in post-frame analysis is that it is circular. Circular reasoning is the logical error of assuming what you are trying to prove. An example is: "Only crooks run for public office, thus all elected officials are crooks." The conclusion is only a restatement of the initial

Table 2: Analysis Comparison Deflection & Roof Shear

| | Fixed Base Analog | Spring Analog | Bohnhoff's Analog |
|---|---|---|---|
| Kpw, Windward Stiffness | 51.8 pli | 33.6 pli | 39.9 pli |
| Rew, Windward Eave Load | 446.3 lbf | 497.7 lbf | 480.5 lbf |
| Kpl, Leeward Stiffness | 51.8 pli | 9.6 pli | 10.6 pli |
| Rel, Leeward Eave Load | -167.4 lbf | -239.5 lbf | -240.4 lbf |
| Kp total | 103.6 pli | 43.2 pli | 50.5 pli |
| Re total including roof | 1095.6 lbf | 1218.6 lbf | 1202.3 lbf |
| Maximum Frame Deflection | 1.03" | 1.20" | 1.18" |
| Maximum Roof Shear | 4028.5 lbf | 5310 lbf | 5740 lbf |

Table 3: Analysis Comparison Leeward Non-constrained Post

| | Fixed Base Analog | Spring Analog | Bohnhoff's Analog |
|---|---|---|---|
| External + internal wind | 54.3 plf | 54.3 plf | 54.3 plf |
| Rel, ext + int wind | -284.6 lbf | -407.2 lbf | -408.7 lbf |
| Load resisted by frame | 53.4 lbf (51.8 pli x 1.03") | 10 lbf (trial & error) | 12.5 lbf (10.6 pli x 1.18") |
| Post Shear at Eave | 232.2 lbf | 397.2 lbf (trial & error) | 395.3 lbf |
| Post Shear at Grade | 528.3 lbf | 363.8 lbf (trial & error) | 364.9 lbf |
| Max Moment Mid Height | 496.5 ft-lbf | 1452.7 ft-lbf | 1438.9 ft-lbf |
| Moment at Grade | -2070.6 ft-lbf | 233.5 ft-lbf | 259 ft-lbf |
| Contraflow above Grade | YES | NO | NO |
| Post embedment depth | 4.53 ft (Section 6.5.1 EP-486.1) | 4 ft nh x △ at 16" below grade = 282 psf/ft | 4 ft nh x △ at 16" below grade = 320 psf/ft |

premise. The use of the fixed base analog is like this in that it produces the result that the shear and moment at grade will always reinforce, never counteract, each other. McGuire (1998) pointed out that this assumption is inherent in the derivation of the post embedment formulas. They assume the soil pressure distribution which is characteristic of a simple cantilever. Restated explicitly it is: "The fixed base analog always predicts that embedded posts behave like simple cantilevered posts, thus all posts behave like simple cantilevers."

This is nonsense. The reason an analog is developed is to determine the internal forces in a member by calculating its deformations. With a fixed base analog, zero deformation corresponds to any value from zero stress to infinite stress. The very first test of a model of an embedded post is how well it predicts the pressure distribution in the soil. The fixed base analog fails this task miserably.

## Expedient Design

Fortunately, the IBC in Section 2306.1 adopts ASABE EP-486.1. This Engineering Practice implicitly (if not explicitly) gives a designer the tools he needs to use a more rational analog which is consistent with the assumption that soil is an elastic material and its strength and stiffness increase with depth below grade. Dr. David Bohnhoff (1992) presented such a rational analog in a paper published almost 20 years ago. Bohnhoff presented equations "for estimating frame stiffness and eave loads for diaphragm analysis of post-frame buildings. Those equations developed for embedded posts take into account soil stiffness." Bohnhoff began by considering an embedded post analog consisting of two pinned supports below grade which are unyielding in the horizontal direction. Although this analog has not been directly considered heretofore in this paper, one can see that it is in many ways similar to a fixed base analog. Bohnhoff stated: "This analog does not allow realistic post rotation and ignores the influence of soil properties on frame stiffness." As a remedy, Bohnhoff went back to the initial assumptions of the embedment formulas and derived equations for frame stiffness using the soil as an elastic material.

Later McGuire (1998) used the work of Bohnhoff and Meador (1997) to develop an analog modeling soil as a series of springs supporting the post below grade. The springs were calibrated to agree with the increasingly stiff soil as embedment depth increased. This analog was suitable for use in a matrix analysis computer program. McGuire's results confirmed Bohnhoff's equations, and McGuire was able to identify the error introduced by assumption #3 that the post is rigid below grade. Since most designers use matrix analysis programs, it would seem that the stage was set before the turn of the millennium for the fixed base analog to become extinct.

However, it is a fact of life that to be expedient a structural design method must be not only accurate, but efficient. The work it takes to get the result must not be burdensome, and it is burdensome to set up each embedded post as supported by a series of springs in a matrix analysis program. (But there is a limit to how much accuracy can be ethically sacrificed for the sake of speed.) Some mostly unsuccessful work was done to develop a less burdensome spring model for use in matrix analysis programs. At

least this author abandoned this project because he found it unnecessary. Matrix analysis programs are a powerful tool for engineers. They are general and can be applied to all sorts of strange situations. But most of the time they are like using your deer rifle to hunt squirrels — they are way too much gun. The vast majority of post-frame buildings can be quickly analyzed using Bohnhoff's original soil stiffness equations programmed into a simple spreadsheet. These values can be entered into the Diaphragm and Frame Inspection program, or in the same spreadsheet compatible eave deflections can easily be solved using the Simple Beam Analogy equations presented in Section 9.5.3 of the Post-Frame Building Design Manual (2000). If used within the limits for which they were developed, these equations give the same results as matrix analysis methods such as DAFI (Bohnhoff, 1992).

## Errors

To get a sense of the differences in results, let's consider the lateral wind load analysis of 40' wide x 80' long x 14' tall post-frame building as described in **Table 1**. Further let's analyze it with 3 different analogs: fixed base, Bohnhoff's and the spring model. The frame stiffness of the fixed base and the spring analogs were calculated using PPSA4 (Triche and Suddarth, 1993). Compatible deflections were calculated using DAFI (Bohnhoff, 1992). **Table 2** summarizes the calculated deflections and roof shears. **Table 3** is a comparative analysis of the leeward non-constrained post at the point of maximum roof diaphragm deflection. Since internal pressures cancel and produce no net lateral force, deflections were calculated using the external wind only. In the leeward post analysis, positive wind internal pressure has been added to the external wind pressures.

**Table 3** shows that using a fixed base analog leads to an underestimation of the positive moment in the leeward post of almost 200 percent. Although the maximum moment in the fixed base analog is still larger than in the other two analogs, location does matter. At the base of the post, it is generally accepted that the post is braced against buckling under com-
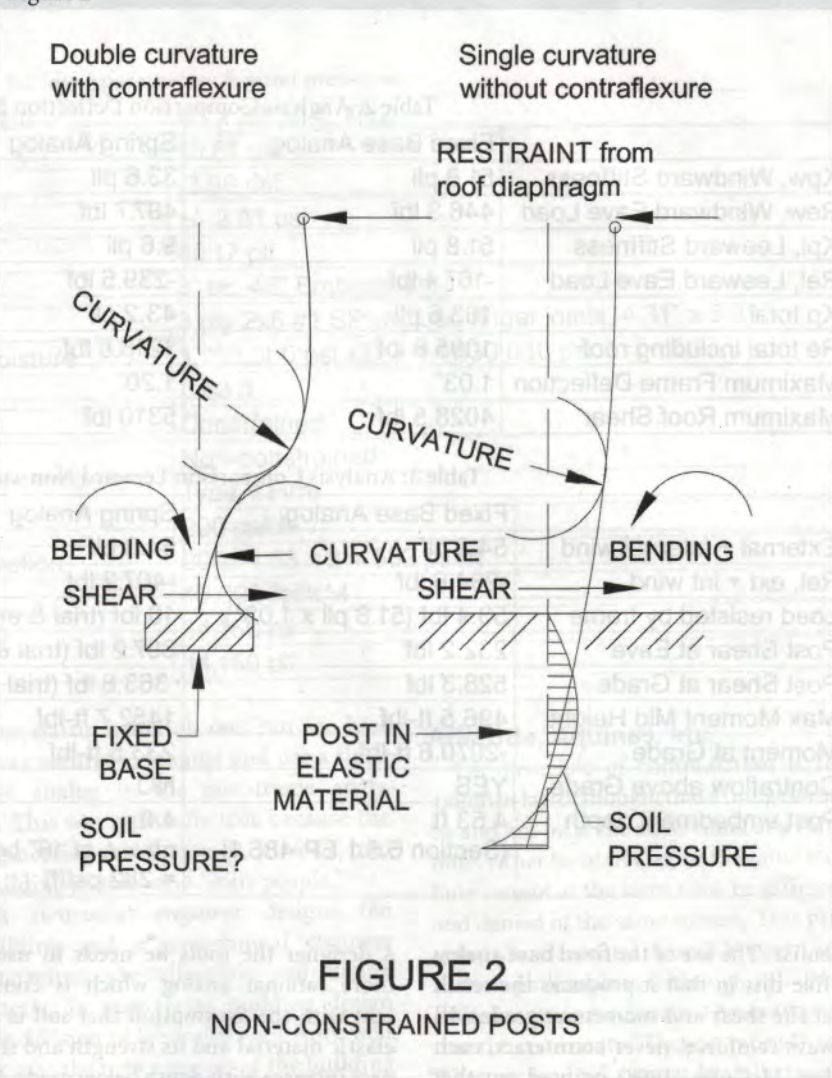


**FIGURE 2**
NON-CONSTRAINED POSTS

pression, whereas at mid-height it is not.

The larger base moments predicted by the fixed base analog would also lead the designer to conclude that for this example, 4' is not an adequate embedment depth to resist lateral loads, whereas the other two analogs show that 4' embedment is more than adequate.

Finally, the point of contraflexure predicted by the fixed base analog could tempt a designer to locate a post splice at this point and neglect bending. The other two analogs show that there is no point of contraflexure above grade so that bending must be considered at all locations.

Figure 2 illustrates this result.

## Conclusion

Analogs must not presume, but predict.

## References

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