



# GroundED

THE SUPPORTWORKS NEWSLETTER FOR DESIGN PROFESSIONALS

## How to Evaluate Pile Buckling Load Using IBC Methodology

Often the engineers at Supportworks will make recommendations for shaft sizes of helical piles and push piers based on the pile buckling potential. Pile buckling may occur when there are very soft or very loose soil conditions, when liquefaction of the soil is possible during earthquake events, or when sections of piling are exposed above grade.

Although there are many methods to evaluate pile buckling, this article focuses on a methodology specified in the International Building Code (IBC). Specifically, the 2009, 2012 and 2015 IBC states, "Any soil other than fluid soil shall be deemed to afford sufficient lateral support to prevent buckling of deep foundation elements... Where deep foundation elements stand unbraced in air, water, or fluid soils, it shall be permitted to consider them laterally supported at a point 5 feet into stiff soil or 10 feet into soft soil..."

This code section still leaves some ambiguity because there are no definitions provided for a fluid soil, soft soil or firm soil. However, the International Code Council (ICC) Acceptance Criteria AC358 defines firm, soft and fluid soils as, "Firm soils shall be defined as any soil with a Standard Penetration Test blow count of five or greater. Soft soils shall be defined as any soil with a Standard Penetration Test blow count greater than zero and less than five. Fluid soils shall be defined as any soil with a Standard Penetration Test blow count of zero [weight of hammer (WOH) or weight of rods (WOR).] Standard Penetration Test blow count shall be determined in accordance with ASTM D1586."

Since the IBC requires the pile to be designed as a free-standing column with an unsupported length as determined above, a converted Euler equation from the American Institute of Steel Construction (AISC) Specification for Structural Steel Buildings (AISC 360) may be used, which provides an estimation of the elastic critical buckling load for a long, slender, ideal column:

$$P_e = \frac{\pi^2 EI}{(KL)^2}$$

Where,

$P_e$  = Elastic Critical Buckling Load

$E$  = Modulus of Elasticity of the Pile Shaft Cross Section

$I$  = Moment of Inertia of the Pile Shaft Cross Section

$K$  = Effective Length Factor

$L$  = Unsupported Length

An ideal column is one that is perfectly straight, homogeneous and free from any initial residual stresses. Since an ideal column can only exist in theory, AISC 360 utilizes an adjustment coefficient to normalize the theoretical elastic buckling with the results observed in testing research. The elastic critical buckling load then becomes:

$$P_{crit} = 0.877P_e$$

Where,

$P_{crit}$  = AISC Adjusted Elastic Critical Buckling Load

It should be noted that the Euler Method is only suitable for intermediate length to longer columns that produce values of  $P_e$  less than  $0.44*F_y*A$ . When the Euler load ( $P_e$ ) is greater than this value, then inelastic buckling will govern and  $P_{crit}$  becomes:

$$P_{crit} = \left[ 0.658 \frac{F_y A}{P_e} \right] F_y A$$

Where,

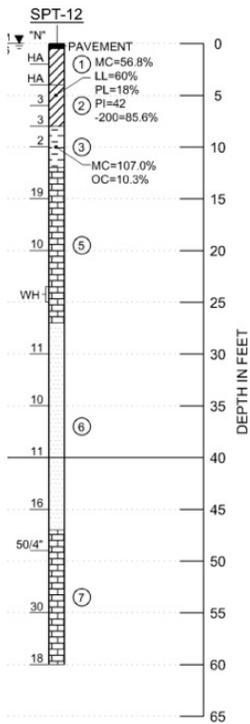
$F_y$  = Yield Stress

$A$  = Cross-Sectional Area

$P_{crit}$  is divided by a factor of safety (FOS) to determine the allowable compressive strength of the pile, which is then compared to the service compression load. A FOS (also referred to as  $\Omega$ ) of 1.67 would be consistent with AISC design methods, although helical pile designers routinely use factors of safety in the range of 1.5 to 2.0.

Now let's do an example of how we would design for buckling per the IBC. Let's consider a helical pile with a service compression load (allowable load) of 20 kips with a pile head depth of 5 feet, tip depth of 48 feet and a soil profile as shown. Standard AISC factors of safety are specified for the analysis.

*Continued on next page*



**Step 1: Determine the unsupported length (L).** The buckling analysis requires the determination of an unsupported pile length based on either soil strengths above and below the zone of fluid soils, or the amount of pile shaft that is exposed above grade and the soil strengths below. The soil boring log shows that the weight of hammer zone (identified as WH) could conservatively be as much as 10 feet thick with firm soil above (SPT blow count of 10) and below (SPT blow count of 11). Based on this soil profile, the unsupported length for our buckling analysis would be 20 feet.

**Step 2: Identify the material properties for various shafts.** Let's consider the Supportworks HP288 and HP350 hollow round shafts. The HP288 has a nominal 2.875-inch outer diameter (OD) by 0.276-inch wall thickness and the HP350 shaft has a nominal 3.5-inch OD by 0.340-inch wall thickness. The following mechanical properties are based on galvanized steel after a 50-year

corrosion loss per AC358 and can be found in the 2017 Supportworks Technical Manual:

Properties	HP288	HP350
OD (in)	2.865	3.490
ID (in)	2.371	2.876
A (in <sup>2</sup> )	2.03	3.06
F <sub>y</sub> (ksi)	60	65
E (ksi)	29,000	29,000
I (in <sup>4</sup> )	1.76	3.91

**Step 3: Determine the appropriate design K value.** For this project, a design K value of 0.65 is used for fixed-fixed end conditions since the pile head is above the 5 foot length to fixity from the top of the fluid soil zone and the helix plates are below the 5 foot length to fixity from the bottom of the fluid zone. Other end conditions may occur when the pile head is not located above the length to fixity from the fluid zone, where shafts are exposed above grade or where the helix plates are not founded below the required length to fixity. The recommended design K values for various end conditions are shown in Table C-C2.2 from AISC 360.

Buckled shape of column is shown by dashed line.	(a)	(b)	(c)	(d)	(e)	(f)
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10	2.0
End condition code						

**Step 4: Calculate the allowable compressive strength.** Using traditional AISC factors of safety for buckling, we need a shaft that has an allowable compressive strength of at least 20 kips. Begin by using the Euler equation and AISC adjustment coefficient assuming elastic behavior.

For the HP288 shaft, the elastic critical buckling load,

$$P_e = \left[ \frac{\pi^2 EI}{(KL)^2} \right] = \left[ \frac{3.14^2 \cdot 29,000 \cdot 1.76}{(0.65 \cdot 20 \cdot 12)^2} \right] = 20.6 \text{ kips}$$

and the allowable compressive strength,

$$P_{crit}/\Omega = 0.877 \cdot P_e/\Omega = 0.877 \cdot 20.6/1.67 = 10.8 \text{ kips} < 20 \text{ kips.}$$

Since the HP288 shaft does not have an allowable compressive strength of at least 20 kips, evaluate the HP350 shaft:

For the HP350 shaft, the elastic critical buckling load,

$$P_e = \left[ \frac{3.14^2 \cdot 29,000 \cdot 3.91}{(0.65 \cdot 20 \cdot 12)^2} \right] = 46.0 \text{ kips}$$

and the allowable compressive strength,

$$P_{crit}/\Omega = 0.877 \cdot 46.0/1.67 = 24.2 \text{ kips} > 20 \text{ kips.}$$

Since the HP350 shaft has an allowable compressive strength greater than 20.0 kips, it is selected for the project.

**Step 5: Verify elastic buckling.** The value of 0.44\*F<sub>y</sub>\*A is 87.5 kips for the HP350 shaft. Since this value is greater than the elastic critical buckling load of 46.0 kips, elastic buckling would occur and the use of the Euler equation (with modification) is appropriate.

The method described in this article for buckling evaluation may not account for dynamic loading, pile geometry changes and stiffness variations due to pile shaft couplings. The design professional should be aware of the buckling design method assumptions as they apply to the pile design. The reader may want to reference the 2017 Supportworks Technical Manual for a more thorough explanation of pile buckling analysis with other design methods. An electronic version of the Technical Manual is available on the Supportworks commercial website ([www.OnStableGround.com](http://www.OnStableGround.com)).

**Project:** KETV Historic Building Remodel

**Location:** Omaha, NE

**Pier Installer:** Thrasher, Inc.

**Challenge:** The local ABC affiliate, KETV, acquired the historic Burlington Train Station to be remodeled as a broadcast and web-media facility. This remodel included the re-support of an interior multi-wythe brick wall. The existing wall was supported by a continuous pair of steel channels spanning approximately 10 feet between brick piers along the wall length. The project designers proposed removing the steel channels to support the existing wall on a continuous grade beam supported by a deep foundation system.

A geotechnical investigation performed for the proposed renovations included the advancement of 13 soil borings to a maximum depth of 95 feet below grade. The general subsurface profile consisted of approximately 80 feet of soft to stiff lean clay underlain by 9.5 feet of sand with cobbles. The sand was underlain by a one-foot-thick layer of weathered shale over weathered limestone to the explored depth.

**Solution:** Helical piles were chosen as the ideal deep foundation solution given the limited access and tight working area. The helical pile configuration consisted of a square-bar "stinger" lead section, Model 200 (2.00-inch round corner square bar) with an 8"-10"-12" triple-helix arrangement, transitioning (via a special welded coupler) to a Model 350 (3.50-inch OD by 0.340-inch wall) hollow round shaft extension with a single 14-inch helix plate. The remaining lengths of the piles consisted of blank Model 350 extensions. The square-to-round "stinger" lead section was used to better penetrate the cobbly sand and weathered shale, while the helix plate configuration was selected to achieve the required torque prior to "spinning off" on the limestone. The 8-inch and 10-inch helix plates were each 0.5-inch thick and utilized a V-style cut on the leading edge to help the piles advance through the cobbles and also aid in penetrating into the anticipated shale layer. The helical piles were advanced to achieve torque-correlated ultimate capacities of at least twice the design working loads ( $FOS \geq 2$ ).

The installed piles were fitted with new construction brackets and cast into T-shaped concrete saddle beams spaced along and perpendicular to the wall. The helical piles and saddle beams were positioned to avoid the existing brick piers. The "T" shape of the beams was required to install two helical piles on one end and a single helical pile on the other to resist the asymmetrical loading on the beams. With the saddle beams constructed, steel I-beams were placed through penetrations in the lower sections of the wall. Hydraulic jacks were located on the saddle beams to support the ends of the I-beams, thereby unloading the original steel channels. The channels were removed and a new concrete grade beam was constructed below the wall. The wall loads were then transferred to the new grade and saddle beams, and the hydraulic jacks and steel beams were removed.



Limited access; product staged



Existing brick piers supporting steel channels



Installing stinger lead section



Piles installed within saddle beam excavation and fitted with new construction brackets



Steel beams and hydraulic cylinders positioned to unload existing foundations

# HelixPro<sup>®</sup> 2.0 Design Software

is a state-of-the-art program that allows you to calculate bearing and uplift capacities of Supportworks helical piles as well as tension capacities of Supportworks helical tiebacks as they pertain to specific site and soil parameters.

Register today to use this FREE state-of-the-art software program: [www.helixpro.supportworks.com](http://www.helixpro.supportworks.com)

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# What's inside

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## How to Evaluate Pile Buckling Load Using IBC Methodology

### Featured Case Study:



KETV Historic Building Remodel - Omaha, NE  
Thrasher, Inc.

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