Pile Foundations of Noise Barriers and Highway Signs

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Extended Abstract

STRUCTURAL SUPPORTS

The main elements of the street furniture are the highway signs, luminaires, traffic signals, variable message signs (VMS) and road traffic noise reducing devices.

These types of devices are erected at the roadside of or above highways and require specific structural supports that are categorized as follows:

a) Sign support structures (overhead balanced cantilevers, overhead unbalanced cantilevers, overhead cantilever, overhead bridge, overhead bridge with cantilever, roadside sign, signs mounted on a grade separation structure);

b) Luminaire support structures (that include typical poles with luminaire arms, typical poles with luminaires mounted at pole top, and high-level luminaire supports, both truss type and pole type);

c) Traffic signal support structures (combination cantilever arm mounted luminaires and traffic signals, cantilever arm mounted traffic signals, pole top-mounted traffic signals, bridge mounted traffic signals, span wire mounted traffic signals);

d) combination structures which are structural supports that combine any of the functions described above.

Steel, aluminum alloys, fiber-reinforced composite (FRC) and wood are the primary materials used for structural supports.

The minimum values of the “clear zone distances” and also size, height and location of structural supports respect to the carriageway, in each Country are established by regulations and guidelines.

The structural analysis of each part of the structural supports, and their foundations, needs the evaluation of loads and forces. Particularly, it must be computed the dead load (weight of the structural support, including hoisting devices and walkways provided for servicing of luminaires or signs), the ice load (applied around the surfaces of the structural supports, traffic signals, horizontal supports, and luminaires) and the wind load (pressure of the wind acting horizontally on the supports, signs, luminaires, traffic signals, and other attachments).

With the aim to produce the maximum load effect, the structures should be proportioned for the combination of the above-mentioned loads, in accordance to the criteria specified in the guidelines as - only for example - in the AASHTO Standard and Specifications (2013) and in the NCHRP Report 494 (2003).

Instead, a detailed methodology for calculating wind load on noise reducing devices has been codified in the European Standard FprEN 1794-1:2010.

In addition, all structural supports should be examined taking into account the effects of corrosion and fatigue.

Structural supports that are susceptible to damaging vibrations and not designed for fatigue should be equipped with appropriate damping or energy-absorbing devices.

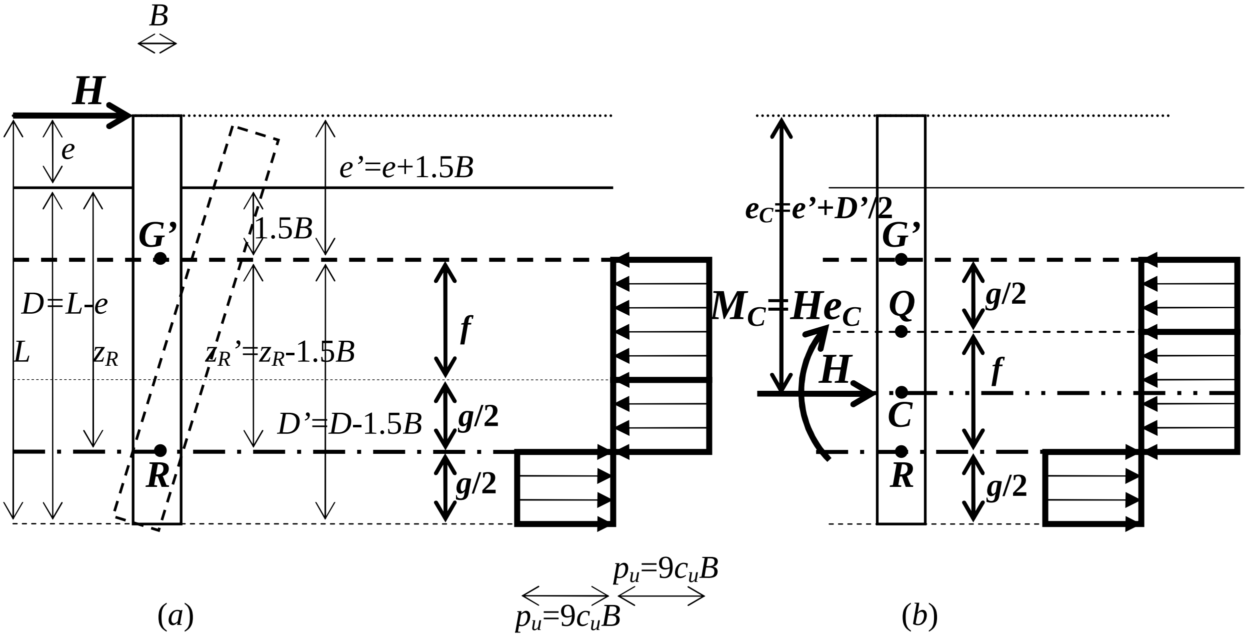
As concerns the foundations , their rotation, and overall stability should be estimated and controlled to alleviate the risk of failure of the entire structure and to ensure the road safety.

The selection of foundation type and its dimensions should be established on considerations such as the soil properties (allowable values of soil pressure), magnitude and direction of loading.

Therefore, the design of foundations require the use of closed-form models or simulation techniques, traditionally used in structural and geotechnical engineering, as clearly explained in the aforementioned guidelines.

BROMS ANALYSIS REVISITED

The Lateral Resistance of short (rigid) transversely loaded piles, such as the pile foundations of Noise Barriers and Highway Signs is usually determined following the conventional simplified Broms approach (1964). In case of a free head (unrestrained) pile in undrained clay (Tresca medium) the scheme is the one in Fig. 1.a, with an equivalent eccentricity (load eccentricity with respect to the beginning of soil reaction according to the Broms simplified assumption) $e' = e + 1.5B$ and an equivalent shaft depth $D' = D - 1.5B$ (see e.g. Mayne et al 1992), e being the actual eccentricity, B the pile diameter, D the true shaft depth from the ground level and $L = D + e$ the pile total length. According to the Broms simplified hypothesis, the ultimate lateral soil reaction per unit pile length p_u is assumed equal to zero to a depth 1.5 B, and then constant and equal to $9c_uB$.



(*a*) (*b*)

FIGURE 1. Lateral Resistance of free head rigid pile in Tresca medium; (*a*) classical Broms schematization, (*b*) revisited structural (metal plasticity) combined bending and normal force approach.

The unknowns f and H, together with g

$$g = D' - f = D - 1.5B - f \tag{1}$$

are easily obtained from the moment equilibrium about the loading point

$$f\left(f/2 + e'\right) - g^2/4 = f\left(f/2 + e'\right) - \left(D - 1.5B - f\right)^2/4 = 0 \tag{2}$$

and the force equilibrium

$$H - 9c_u Bf = 0 \tag{3}$$

The scheme of Fig. 1.a looks very similar to the one in structural metal plasticity, of the combined normal force-bending moment for a steel rectangular section at the ultimate plastic state, with the neutral axis in the role of the axis or rotation (point R at depth z_R). In this case the stresses are reconsidered as in Fig. 1.b, separated in two distinct zones, a central core (extent f) equilibrating the normal force applied at the centroid of the section *BD'*, and the two remaining peripherical parts (each of extent $g/2$) constituting a couple which balances the moment M_C

$$M_C = He_C \tag{4}$$

e_C being the arm of H about C. The force equilibrium being still formally written as Eq. (3), but with f denoting now the core (central part) of soil reaction, the moment equilibrium is simply written as

$$M_C = He_C = 9c_u Bg/2(D' - g/2) = 9c_u B(D' - f)(D' + f)/4 \tag{5}$$

Introducing the ultimate value $H_u = 9c_u BD'$ of H corresponding to the fully restrained (fixed head) case (e_C =0, pure normal stress in the combined loading problem) Eqs. (3) and (5) can be put in the form

$$\frac{M_C}{H_u D'} = \frac{1}{4}\left[1 - \left(\frac{H}{H_u}\right)^2\right] \tag{6}$$

namely the well known Girkmann parabola (Girkmann 1931), with the corresponding H-M_C plot representation (Fig.2 a) (see e.g. Jirázek and Bažant 2002, Lubliner 2006, Zyczkowski 1981).

The symmetric Girkmann's parabola can be transformed into the more useful H-$M_{G'}$ representation in terms of the moment $M_{G'} = H\,e'$ about the point G' (beginning of soil reaction according to the Broms scheme) by writing

$$M_C = He_C = H(e' + D'/2) = M_{G'} + HD'/2 \tag{7}$$

and then

$$\frac{M_{G'}}{H_u D'} = \frac{1}{4}\left[1 - \left(\frac{H}{H_u}\right)^2\right] - \frac{1}{2}\frac{H}{H_u} \tag{8}$$

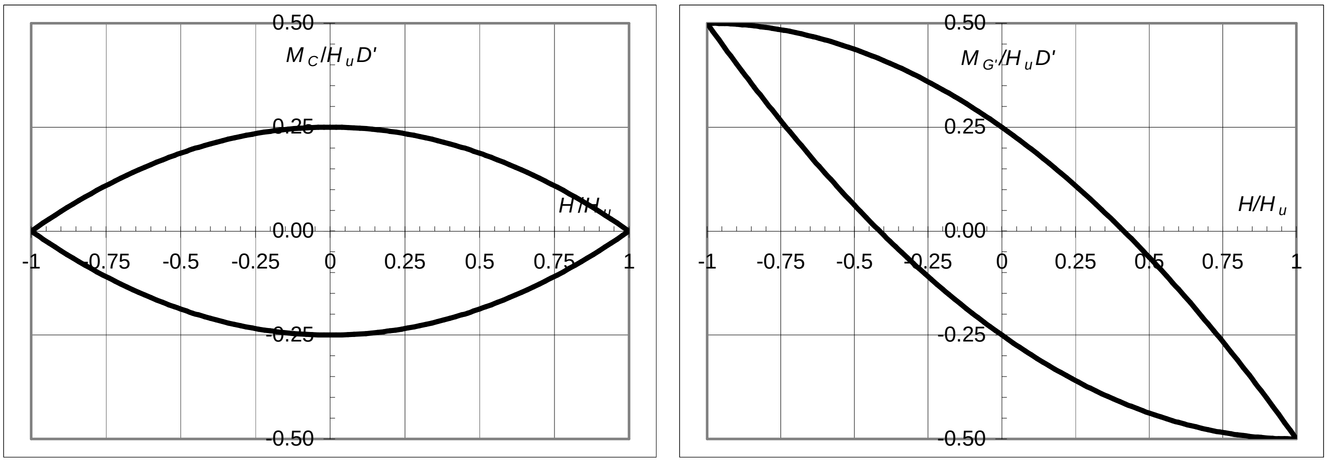
The corresponding graph in Fig.2.b can be compared with the one in Poulos Davis (1980). By eliminating M_C from Eqs (6) and (7) a direct formula for H can be obtained, namely

$$\frac{H}{H_u} = -\left(1 + 2\frac{e'}{D'}\right) + \sqrt{\left(1 + 2\frac{e'}{D'}\right)^2 + 1} \tag{9}$$

and similarly the expression for the equivalent depth of rotation $z_r' = z_r - 1.5\,B$ (fig.1a)

$$\frac{z_r'}{D'} = -\frac{e'}{D'} + \frac{1}{2}\sqrt{\left(1+2\frac{e'}{D'}\right)^2 + 1} \tag{10}$$

(compare with Poulos Davis 1980 and Mayne et al 1992).



(*a*) (*b*)

FIGURE 2 . Transverse load-moment domain (*a*) with reference to the centroid C (Girkmann parabola); (*b*) referred to the point G’ (equivalent ground level in accordance with Broms approximation).

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