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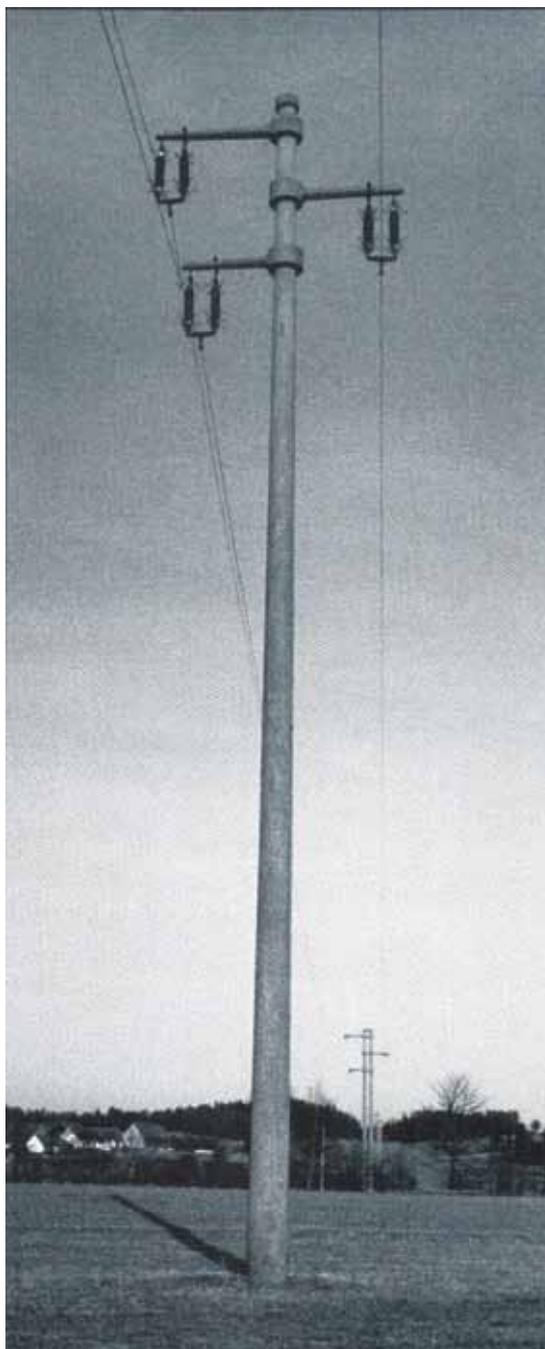
High-strength materials for spun concrete poles

Design requirements for poles determine the material properties

The American Concrete Institute (ACI)¹ defines high-strength concrete as concrete with a specified compressive strength f'_c of at least 8000 psi (55 MPa). ACI adopted this value because it represents a strength at which special measures are required in the production of the concrete. In some instances, special structural design requirements also pertain. However, by using spinning technology coupled with high-quality materials, concrete pole manufacturers routinely achieve concrete strengths about twice that.

High-performance concrete is a necessity for concrete utility poles for a variety of reasons. These lifeline structures are often placed in harsh environments where durability is essential. High strength is needed to produce an efficient and aesthetically pleasing design with the smallest possible diameter, wall thickness, and concrete cover. High strength and light weight make the pole easier to transport and erect in the field. The price of concrete per cubic yard, or cubic meter, increases relatively less than the increase in strength, which gives higher-strength concrete an economic edge in terms of strength per unit cost.

In concrete poles, applied loads can occur from any direction because wind is the primary environmental load. To resist these loads, the cross section is symmetrically reinforced. High-strength prestressing steel strand is used to mobilize the full concrete cross section. Symmetrical prestressing induces uniform compressive stresses in the concrete that will prevent cracking under service loads. The ultimate strength f_{pu} of the strand is used to resist the ultimate design loads. Unstressed slack strand may be incorporated to increase the moment capacity of the cross section.



The first spun-cast concrete pole, installed in Germany in 1924, is still in service. Photo courtesy of Valmont Industries, Inc.



In a hybrid pole, the concrete base is extended by slipping on one or more tubular steel sections. Hybrid poles support transmission lines, sports lighting, and microwave or cellular telephone antennas. By combining the advantages of both concrete and steel, the hybrid pole provides for longer lengths, higher load capacity, and greater ease of handling and construction. The spun-cast concrete base provides an economical foundation and enhanced durability near the ground line. Source: Foust, Earl R., W. J. Oliphant, F. H. Fouad, and K. L. Sharpless. Multiple-Part Pole. US Patent Number 6705058, issued March 16, 2004. Photo courtesy of Valmont Industries, Inc.



Reverse tapered spun concrete poles also allow for taller poles and lighter weight. In addition to the improved aesthetics, the construction allows for direct embedment in the soil and results in reduced transportation and installation costs. Photo courtesy of Valmont Industries, Inc.

Although development of higher-strength steel has lagged behind that of concrete, prestressing strand with f_{pu} greater than 270 ksi (1900 MPa) developed in the early 2000s and is being used to produce poles with higher capacity. As in the case of concrete, the unit price of the strand does not increase at the same rate as the strength, which contributes to economy and design efficiency. The use of higher-strength strand has been employed to provide greater moment capacity for a given cross section. This can result in the ability to carry higher loads or the use of reduced cross sections without an increase in the required steel area. Alternatively, higher-strength strand can result in using fewer strands, which contributes to improved constructability and reduced congestion of reinforcement.

Centrifugal casting

Centrifugal casting provides significant benefits. Concrete is flung against the interior surface of the conical steel mold by centrifugal action to form a dense, hard concrete wall. The fresh concrete is subjected to high centrifugal forces (as high as 60 Gs), which compact the material against the interior of the steel mold and expel excess water from the mixture. The water-cement ratio, initially about 0.35, is reduced to 0.25 or less, which leads to a dense, low-porosity, hydrated cement paste. In principal, centrifugal casting is similar to other methods of dewatering concrete in that the “water of convenience” is removed from the concrete after placement. This water permits easier mixing and placement of the concrete and is then removed to make the concrete denser and stronger.

Unlike other methods of dewatering concrete, which can create voids or channels where the water was removed, spinning compacts the concrete. The exceptional mechanical properties of centrifugally cast concrete cannot be achieved using conventional concrete placement methods. Research²⁻⁶ comparing spun cylinders to statically cast ones has shown that for the same concrete mixture, the compressive strength of spun concrete can exceed that of conventionally cast concrete by 30% or more. The increased compressive strength due to spinning can be used to advantage in design.

Spun concrete is highly durable and can withstand harsh environments because of its low permeability. The dense spun concrete provides superior protection for the steel reinforcement against the ingress of chlorides and other harmful chemicals; for this reason, a concrete cover as small as $\frac{3}{8}$ in. (16 mm) has commonly been used in poles across the world with excellent performance over many years of service.²⁻⁶



Horizontal deflection test of 115 ft (35 m) spun concrete pole. Once the load was removed, the pole returned to its original shape and the cracks closed. The pole was later installed. Photo by Fouad H. Fouad.



A communication pole is camouflaged as a tree to blend in with its surroundings. Photo courtesy of Valmont Industries, Inc.

Foundations

Concrete poles are commonly embedded directly in soil with no additional protection required below grade. The pole is placed in an excavated hole and then backfilled with compacted native soil, select rock, or

concrete depending on soil conditions and the anticipated performance of the foundation. Where the ground line moments are large and the soil is weak, it is usually desirable to use a drilled pier foundation or a precast concrete cylinder pile where the pole is placed inside the pile and the annulus is filled with a suitable backfill. The durability of spun concrete in direct contact with soil has been demonstrated through many years of service due to the ability of the spun concrete to resist corrosion, fire, and other severe service conditions.³⁻⁵ Special measures may be required to protect concrete poles in direct contact with the sulfate soils of the western United States and Canada.

Recent innovations

Innovations in spun concrete pole design and manufacture have led to numerous new applications. In addition to supporting electrical lines, traffic signals, and lighting devices, spun-cast concrete poles are being used to support antenna structures, cellular phone systems, and wind turbines.

References

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Notation

f'_c = specified compressive strength of concrete
 f_{pu} = ultimate strength of prestressing strand



Concrete poles support overhead catenary wires for high-speed rail. Photo courtesy of Valmont Industries, Inc.



Wind turbines up to 1.2 MW in capacity have been supported on concrete poles in northern Europe. Future improvements in wind-turbine technology, coupled with anticipated increases in oil prices and public concern over pollution from burning fossil fuels, may result in the spread of wind farms and, hence, the need for large concrete poles to support the massive turbines. Photo courtesy of Valmont Industries, Inc.

CONCRETE POLES 100 YEARS AGO

From *Handbook on Overhead Line Construction*, published in 1914, we get a glimpse of how cement and concrete have changed in the past hundred years. Modern cements are formulated with higher lime (CaO) contents and are more finely ground to attain in hours the strengths it took months to achieve in 1914.

The most commonly used mixture is 1:2:4 Portland cement, sand, and broken stone or gravel. It should be mixed wet, using carefully selected materials and tamped or churned to eliminate air bubbles, obtain a good surface, and thorough contact with the reinforcement. Such a mixture when well made has an average compressive strength of about 900 pounds per square inch [6 MPa] in seven days, 2400 pounds per square inch [17 MPa] in one month, 3100 pounds per square inch [21 MPa] in three months and 4400 pounds per square inch [30 MPa] in six months.

Naturally it would have required plenty of time and care to remove the forms and handle the precast concrete elements to avoid damage. The authors do not provide specifics as to how to tell when the concrete has become well set.

No attempt should be made to remove the forms until the concrete has obtained a good set, and care must be exercised to prevent injury to the surfaces during such removal. The forms should be kept covered during setting, particularly when exposed to direct sunlight in hot weather, and the concrete pole should be well sprinkled and kept under canvas for some days after the forms have been removed. A freshly made concrete pole cannot be handled or rolled with impunity until it has become well set. Further, the subsequent handling, particularly of long poles, must be done with care, and is preferably done by slings attached at two separate points.

DEWATERING OF CONCRETE

Although not a widespread procedure today, removal of some of the water from freshly placed concrete increases the strength and can be accomplished in various ways. Hollister¹ noted that in the construction of the Baha'i Temple in Evanston, Ill., precast concrete units weighing 3 tons (2.7 tonnes) or more were removed from the forms at 18 hours: "And this with portland cement, not with excessively rich mixtures but with much of the excess water removed *after* placing but *before* the setting of the cement."

Neville² explained one method of removing the excess water. A mixture of medium workability is placed and consolidated. A vacuum is applied to the surface through a porous mat connected to a vacuum pump. The vacuum is maintained for 15 to 25 minutes. It is effective in reducing the water content of the concrete by up to 20% to a depth of 4 to 6 in. (100 to 150 mm). Some of the water extracted leaves behind voids. Even so, the strength of the dewatered concrete has the same relationship to its final water-cement ratio as that of any other concrete.

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WATER-CEMENT RATIO

ACI 211.1¹ outlines the procedure for concrete mixture proportioning by the absolute volume method. The water content is determined by the desired workability given the properties of the aggregate to be used, and the water-cement ratio is determined by the requirements for strength and durability.

The water of hydration for fully hydrated portland cement is about 23% of the mass of the hydrated cement paste, as measured by the nonevaporable water.² Neville³ explained that because pores form in cement hydration products (cement gel) and these pores must be filled with water for hydration to continue, the total amount of water in the mixture must be at least equivalent to a water-cement ratio of 0.42 for full hydration to be possible, or about 0.38 if the concrete is cured under water. This is because the original volume of the unhydrated cement plus water has been filled with hydrated cement gel; that is, the gel-space ratio is 1.0, and there is no more space for cement hydration products to form.

Many modern concretes, including those used in spun concrete poles, have considerably lower water-cement ratios. Thus the cement is only partially hydrated. Neville stated that unhydrated cement does not detract from the strength. Rather, for cement pastes with a gel-space ratio of 1.0, those with a higher proportion of unhydrated cement have a higher strength. Powers and Brownyard⁴ observed that dense cement pastes are stronger the higher the proportion of unhydrated cement. They attributed this to the thinness of the layers of cement gel surrounding the unhydrated cement grains.

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Abstract

Spun concrete poles have been in use for over 100 years. Increases in the strength of concrete and, to a lesser extent, steel for prestressing strand, have made possible innovations in the

poles themselves. These include high-capacity poles, reverse tapered poles, and hybrid poles. The use of high-strength concrete results in more economical poles that can compete successfully with wood- and steel poles. The low porosity and low permeability of high-strength spun concrete make it durable even in harsh environments. Concrete poles can generally be embedded directly in the ground, without the need for a separate foundation. Centrifugal casting removes water from the concrete and compacts it for greater strength and durability.

Keywords

Centrifugal casting, dewatering of concrete, durability, high strength, poles, spun concrete.

Reader comments

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