nt

tress
hortening
ete
f creep but not of shrinkage

rrounding material

ly required for prestressed than for rein-
r strength of 4000 to 5000 psi is generally
or prestressed concrete, while a strength
slump 5000-psi concrete can be obtained
t and a cement content under 7 sacks per
ernal vibration is used.
nover in a pretensioning plant, or fast
hot-air curing, a transfer strength of 3500
strength of over 3000 psi can be attained
ent without special curing.
e behavior and efficiency of prestressed
end of 20 years ranges from one to five
er load (averaging about three times), the
estone aggregates. Of the total amount of
in the first 2 weeks after application of
hs, another one-fourth within a year, and
. Upon removal of the sustained stress,
vered during the same length of time that

nd on moisture conditions, but not on
es with many factors; it may range from
n of the shrinkage strain resulting from
lost water. The amount of shrinkage is
r employed in the mix. Larger size of
paste and harder and denser aggregates
position of the cement also affects the
, shrinkage strain is assumed to be about
employed in prestressed construction.

The rate of shrinkage depends chiefly on weather conditions. If the concrete is left dry, most of the shrinkage will take place during the first 2 or 3 months. When stored in air at 50 percent humidity and 70°F, the rate of shrinkage is comparable with that of creep.

Lightweight concrete has been successfully used in prestressed-concrete construction. It has a lower modulus of rupture than normal-weight concrete and slightly less favorable shrinkage and creep characteristics. However, with the better aggregates these properties are comparable with those of normal-weight concrete.

2. Steel High-tensile steel for prestressing usually takes one of three forms: wires, strands, or bars. Wires for prestressing generally conform to ASTM Specification A421 for Uncoated Stress-Relieved Wire for Prestressed Concrete. They are made from rods produced by the open-hearth or electric-furnace process. After being cold-drawn to size, wires are mechanically straightened and stress-relieved by a continuous low-temperature (about 700°F) heat treatment to produce the prescribed mechanical properties.

The tensile strength and the minimum yield strength (measured by the 1.0 percent total-elongation method) are prescribed in Table 1 for the various sizes of wires. Currently, the ¼-in. wire is the most commonly used.

TABLE 1 Tensile and Yield Strength for Prestressing Wires*

Nominal diam, in.	Remarks	Area, sq in.	Min tensile strength, psi		Min yield strength, psi	
			Type WA	Type BA	Type WA	Type BA
0.192	Gage 6	0.02895	250,000		200,000	
0.196	5 mm	0.03017	250,000	240,000	200,000	192,000
0.250	¼ in.	0.04909	240,000	240,000	192,000	192,000
0.276	7 mm	0.05983	235,000		188,000	

*Type WA for wedge-type anchorage; type BA for button-type anchorage.

A typical stress-strain curve for a stress-relieved ¼-in. wire conforming to ASTM A421 is shown in Fig. 1, with a typical modulus of elasticity between 28,000,000 and 30,000,000 psi. The specified minimum elongation in 10 in. is 4 percent. Typical elongation at

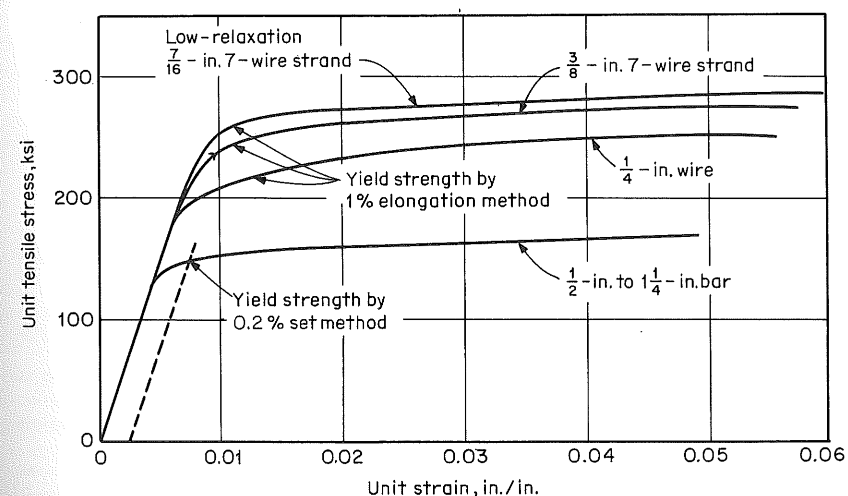

Fig. 1 Typical stress-strain curve for prestressing steels.

rupture is likely to be from 5 to 6 percent.

Strands for prestressing generally conform to ASTM Specification A416 for Uncoated Seven-Wire Stress-Relieved Strand for Prestressed Concrete. While these specifications were intended for pretensioned, bonded construction, they are applicable to posttensioned construction, whether of the bonded or the unbonded type. These strands have a guaranteed minimum ultimate strength of 250,000 psi, with the properties listed in Table 2. A higher-strength steel known as 270K grade, which is more commonly used, has a guaranteed minimum ultimate strength of 270,000 psi (Table 2).

A typical stress-strain curve for a stress-relieved 3/8-in. seven-wire strand (ASTM A416 grade) is shown in Fig. 1, which is also typical for strands of all sizes. For approximate

TABLE 2 Seven-Wire Uncoated Stress-Relieved Strands

Nominal diam, in.	Weight per 1000 ft, lb	Approx area, in.^{2}	Ultimate strength, lb	Yield strength, lb
		250K grade		
1/4	122	0.036	9,000	7,650
5/16	197	0.058	14,500	12,300
3/8	272	0.080	20,000	17,000
7/16	367	0.108	27,000	23,000
1/2	490	0.144	36,000	30,600
0.6	737	0.216	54,000	45,900
		270K grade		
3/8	290	0.085	23,000	19,550
7/16	390	0.115	31,000	26,350
1/2	520	0.153	41,300	35,100
0.6	740	0.217	58,600	49,800
		270K grade (low relaxation)		
3/8	292	0.085	23,000	20,700
7/16	400	0.115	31,000	27,900
1/2	532	0.153	41,300	37,170
0.6	737	0.215	54,000	48,600
		Dyform strand		
5/16	230	0.069	20,000	17,000
3/8	330	0.099	28,000	23,800
7/16	450	0.134	38,000	32,300
1/2	600	0.174	47,000	39,950
0.6	860	0.253	65,000	55,250

calculations, a modulus of elasticity of 27,000,000 psi is often used for ASTM A416 grade and 28,000,000 psi for 270K grade. The specified minimum elongation of the strand is 3.5 percent in a gage length of 24 in. at initial rupture, although typical values are usually in the range of 6 percent. When these strands are galvanized, they are about 15 percent weaker.

Another type of seven-wire strand of 270K grade is the "stabilized" strand, which is produced by a combined process of low-temperature heat treatment and high tension. Because of this special process, the yield strength of the strand is raised and its relaxation is substantially reduced. This type is also called low-relaxation strand.

A "Dyform" seven-wire stress-relieved strand, originated in Great Britain, differs from the regular seven-wire strand in that the outer wires of the Dyform strand are deformed, being run through a die after the stranding operation. It has the advantage of having a greater steel area than that of a regular strand with the same nominal diameter, thus resulting in a larger ultimate tensile strength.

Three-wire stress-relieved strands up to 3/8 in. in diameter and four-wire stress-relieved strand of 7/16 in. in diameter are also available. These strands have the same diameter, steel area, and ultimate-strength requirements as the corresponding seven-wire strands.

High-strength alloy bars for
A722. These bars are usually p
guaranteed ultimate strength, w
strain curve for these bars is sl
elasticity exists only for a limit
25,000,000 and 28,000,000 psi.
The yield strength of high-te
method or the 0.2 percent offset
a minimum yield strength of 85
values are often higher. Mini
specified at 4 percent, with min
properties of high-tensile bars f

3. Grouting For bonding the
posttensioning), cement grout i
corrosion. Entry for the grout i
anchorage heads and cones, or p
injected at one end of the mem
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limited space through which t
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that the pressure on the walls of
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Where larger space between
cement-sand mix is often used
pressure of a few psi may be suff
Freyssinet or Prescon cable, ne
should be employed. Admixtu
bleeding and shrinkage, or prov
sand of 1/64-in. grain size can be a
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pressure generally ranges from
end, that end is plugged and the
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A minimum grout temperature
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Otherwise, difficulties may be e
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claimed to have a very low coeff

METHODS AND SYSTEMS OF PRE

4. Tensioning Methods Metho
groups: (1) mechanical prestres
application of heat, (3) chemical p
Mechanical stressing of the te
sioning and pretensioning. In p
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The capacity of these jacks varie
Gilbert system in England empl
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cables of different sizes. The Le

$$\Delta f_s = E_s \delta = \frac{E_s F_0}{A_c E_c} = \frac{n F_0}{A_c} \tag{1}$$

where $n = E_s/E_c$.

The value of F_0 may not be known exactly. However, the value of the initial prestress F_i before transfer is usually known; hence another solution can be obtained. Using the transformed-section method, with $A_t = A_c + nA_{ps}$,

$$\delta_i = \frac{F_i}{A_c E_c + A_{ps} E_s}$$

$$\Delta f_s = E_s \delta_i = \frac{E_s F_i}{A_c E_c + A_{ps} E_s} = \frac{n F_i}{A_c + n A_{ps}} \tag{2}$$

$$\Delta f_s = \frac{n F_i}{A_t}$$

TABLE 4 Typical Tendons for B.B.R.V. System*

No. of ¼-in. wires	1	14	28	40
Section area of wires, in.²	0.04909	0.687	1.3744	1.963
Max force after anchoring (70% of ultimate), lb	8250	115,500	231,000	330,000
Max jacking force (80% of ultimate), lb	9420	131,880	263,760	376,800
Ultimate strength, lb	11,780	164,920	329,840	471,200
Baseplate, B.B.R.V., in.		6¾ × 6¾	9¼ × 9¼	11 × 11
Baseplate, Prescon, in.		6 × 8½	7 × 12	

*Almost any number of ¼-in. wires up to about 192 for either system.

TABLE 5 Freyssinet System. Cable Characteristics

Wires (0.196 and 0.276 in. diameters)			
Cable size	12/0.196	18/0.196	12/0.276
Nominal steel area, in.²	0.362	0.546	0.718
Ultimate strength, lb	90,000	135,000	168,500
Max jacking force, lb (80% ultimate)	72,000	108,000	135,000
Max force after anchoring, lb (70% ultimate)	63,000	94,500	117,950
Cable weight—sheath not included, lb/ft	1.23	1.85	2.45
Recommended hole diam, in.	1⅛	1½	1½
Anchorage diam, in.	3⅞	4⅞	4⅞
Anchorage length, in.	4	4⅞	4⅞

12-strand (½-in. 7-wire Strands)	
Nominal steel area, in.²	1.73
Ultimate cable strength (1.73 × 250,000 psi), lb	432,000
Max jacking force (80% of ultimate), lb	345,600
Max force after anchoring (70% of ultimate), lb	302,400
Cable weight (sheath not included) lb/ft	5.93
Recommended hole diam (ID), in.	2⅝
Anchorage diam, in.	8¼

TABLE 6 Prestressing Bars

¾	1.50	0.442
⅞	2.04	0.601
1	2.67	0.785
1⅛	3.38	0.994
1¼	4.17	1.227
1⅜	5.05	1.485
⅝	0.98	0.28
1	3.01	0.85
1¼	4.39	1.25
1⅜	5.56	1.58

*Losses due to creep, shrinkage of c
Overtension to $0.8f_{pu}$ is permitted to
†Regular is for minimum ultimate s
‡Special is for minimum ultimate s

TABLE 7 VSL Posttensioning Syst

Unit	No. of strands	Steel area, in.²	Weight, lb/ft
E5-3	2	0.31	1.05
	3	0.46	1.58
E5-4	4	0.61	2.10
E5-7	5	0.77	2.63
	6	0.92	3.15
	7	1.07	3.68
E5-12	8	1.22	4.20
	9	1.38	4.73
	10	1.53	5.25
	11	1.68	5.78
	12	1.84	6.30
E5-19	13	1.99	6.83
	14	2.14	7.35
	15	2.30	7.88
	16	2.45	8.40
	17	2.60	8.93
	18	2.75	9.45
E5-22	19	2.91	9.98
	20	3.06	10.50
	21	3.21	11.03
	22	3.37	11.55
E5-31	23	3.52	12.08
	24	3.67	12.60
	25	3.83	13.13
	26	3.98	13.65
	27	4.13	14.18
	28	4.28	14.70
	29	4.44	15.23
	30	4.59	15.75
	31	4.74	16.28
E5-55	55	8.42	28.88