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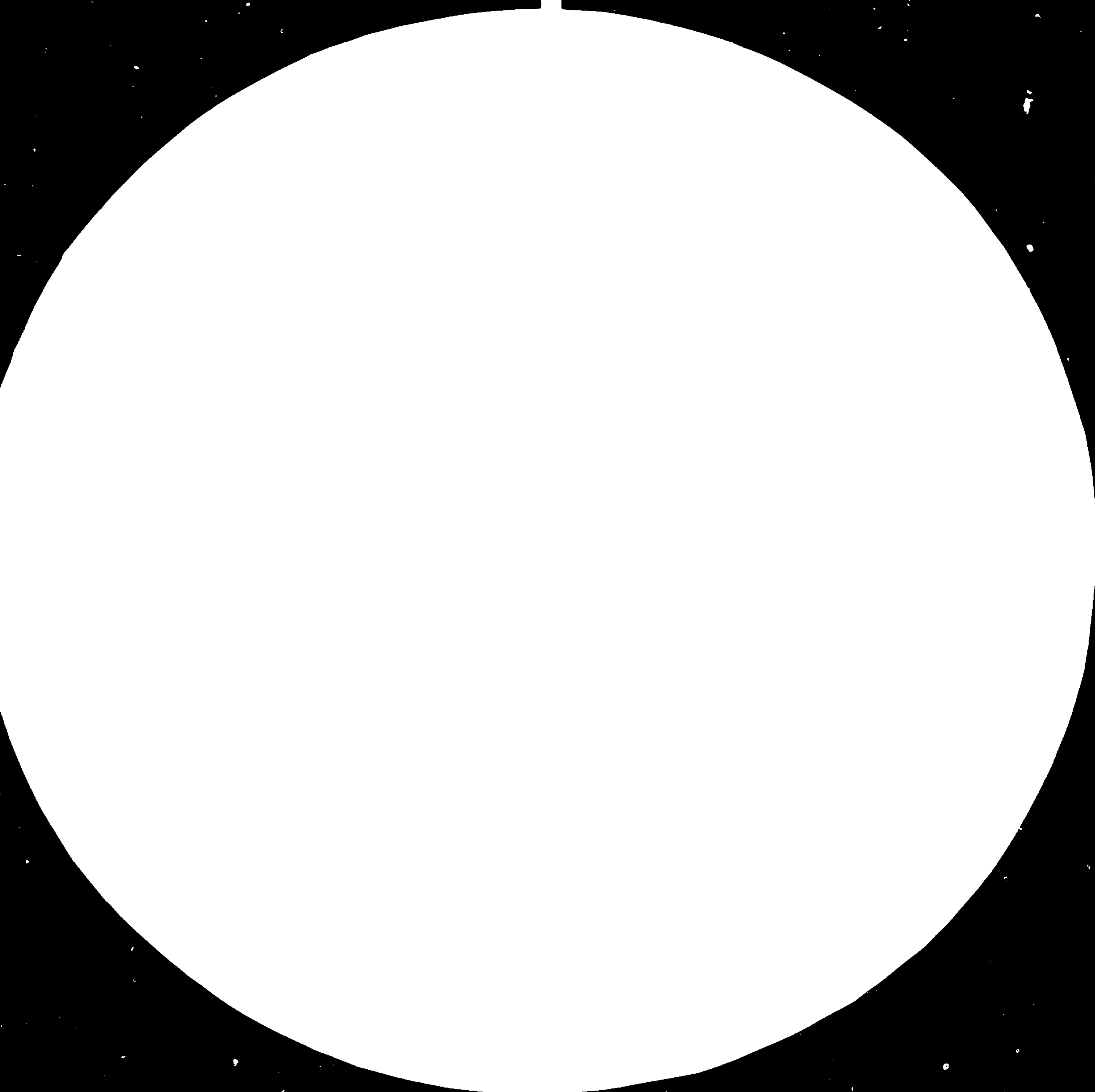
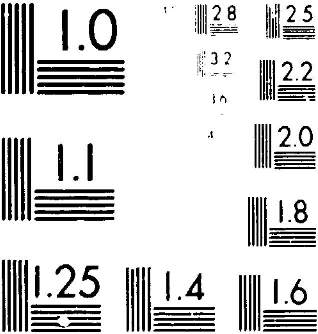
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org





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THE APPLICATION OF PRESTRESSED CONCRETE PIPES IN SMALL HYDRO-ELECTRIC STATIONS*

by

Huang Bingnan**

and

Cai Xuxian**

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** Ministry of Water Conservancy, People's Republic of China.

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Summary

Prestressed concrete pipes have been used in small water power plants with water head less than 218 meters in Zhaoqing Prefecture of Guangdong Province and this application has achieved good results. This paper will present structural design and computation of pipe as well as quality control and examination of prestressed concrete pipe manufactured with three-stage technology centrifugal process.

I. Introduction

Pressure pipes generally used in small water power plants were steel and wooden pipes in the past. The supply of steel stuff did not meet the needs accompanying with the development of the hydro-electric construction. In 1964, consulting the foreign experience, Gaoliang hydro-electric station of Deqing County of Zhaoqing Prefecture, Guangdong Province, successfully used self-made Spigot-and-socket type prestressed concrete pipes instead of steel pipes, and this has spread gradually soon afterwards. Up to now, every county in this prefecture has run a cement pipe plant. These plants have manufactured pressure pipes 76 kilometers in total length for 2,700 hydro-electric units. Among these water power plants, the water head of Huangtongjiang Hydro-electric Station of Deqing County is the highest, which reaches 218 meters. Three 800 kw generating units have been installed, and prestressed concrete pipes 600 millimeters in diameter have been used. At Shuixia Hydro-electric station with a water head of 168 meters in Huaiji County, four 3,000 kw generating units have been installed, and prestressed concrete pipes 1,250-1,300 millimeters in diameter have been adopted.

Prestressed concrete pipes possess following advantages compared with steel pipes: such as, low cost, less amount of pipe steel; convenience for installation; better water sealing of joint; better capability to adapt deformation; less expense for maintenance; long durability; etc. Nevertheless, prestressed concrete pipes have some shortcomings; such as, larger deadweight; easier to be broken due to collision during transportation and installation processes, and these should be overcome by taking adequate measures.

II. Design of Prestressed Concrete Pipe

Prestressed concrete pipe consists of three parts: concrete pipe core reinforced with longitudinal prestressed steel; circumferential prestressed wire wound around the external surface of the pipe core wall; and protective layer.

A. Dimension of Pipe Body and Type of Pipe Joint

1. Dimensions of Concrete Pipe Core

The thickness of pipe core is primarily decided by strength of pipe body and crack-resistant requirement. It must be properly thickened in accordance with the increases in pipe diameter and water head. Through theorectical analysis and practical experience, when concrete strength is higher than No. 500 in grade, Table 1 may be referred to in determining the thickness of pipe.

The length of pipe is determined by following factors: strength; manufacturing technology; transportation and installation; project expense and so on. For pipe diameter over 400 mm, its length may be generally chosen as 4-5 meters; and for that under 300 mm, as 3 meters.

Table 1 Dimension of Thickness of Pipe Core

Design internal water pressure (kg/cm^3)	Internal Diameter of Pipe D (mm)											
	200	300	400	500	600	700	800	900	1000	1100	1200	1300
	Thickness of Pipe Core d (mm)											
1-10	28	35	38	40	45	50	55	60	65	70	75	80
11-15						55	60	65	70	75	80	85
16-20				45	50	60	65	70	80	85	90	95

2. Type of Pipe Joint

The pipe joint adopted was spigot-and-socket joint "model 63" which had been suggested by Constructional Material Scientific Research Institute of the People's Republic of China as shown in Fig. 1. Water sealing ring used is in circular crosssection. The structure of this sort of joint is rather simple. It is convenient in installation and good in water sealing characteristic.

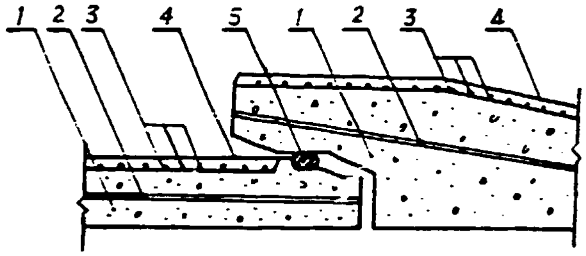

Fig. 1 "Model 63" Spigot-and-socket Joint

1. **Concrete pipe core;**
2. **Longitudinal prestressed steel;**
3. **Circumferential prestressed wire;**
4. **Protective layer;**
5. **Water-sealing rubber ring.**

B. Circumferential Structural Computation of Pipe Body

Pressure pipes generally used in water power plants are open-air pipes, and the major loadings are internal water pressure, dead-weight of pipe body, water weight within the pipe, temperature difference between internal and external surfaces of pipe wall. Since the pipe wall is rather thin, in order to simplify computation, all the stresses induced in pipe wall by various loading are assumed as thin-wall circular pipe. (Although very few of thickness of pipe core listed in Table 1 exceeds thin wall pipe assumptions, but after calculation and comparison, the results of pipes designed according to thick wall pipe and thin wallpipe only differ slightly from each other.)

1. Computation of Circumferential Stress

(1) Tensile stress caused in pipe wall due to internal water pressure

Since protective layer of the pipe made by three-stage process is not subjected to precompressive stress, thus, the internal water pressure taken by the protective layer will not be considered. Therefore the tensile stress caused in pipe wall by internal water pressure is:

$$\sigma = \frac{N}{bd}$$

Where:

N — hoop tension induced in pipe wall (kg), namely $N = pr_o b$;

d — thickness of pipe core (cm);

b — longitudinal unit length of pipe, take $b = 100$ cm;

p — design internal water pressure including water hammer pressure increment) (kg. cm^2)

r_o — Internal radius of pipe (cm).

(2) Pipe wall stress due to dead weight of pipe body and water weight

The internal force induced in pipe wall due to dead weight of pipe body and water weight is related with the position of cross-section position and constructtion method of pipe cushion. Pipe cushions generally used are rigid cushion built with concrete or brick-stone masonry. Cushion of this type is better in circumstance under forces. namely. internal force resulted in pipe wall is rather smaller. The envelope angle of pipe cushion in most pprojects is $2\varnothing = 90° — 135°$ as shown in Fig 2.

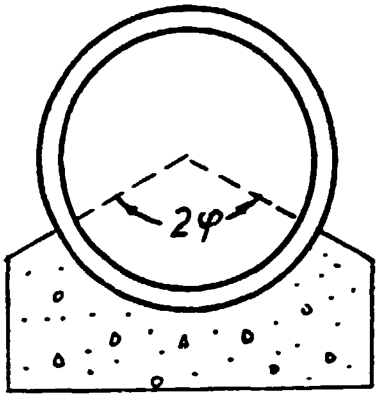

Fig. 2

Because, under the action of various loadings. the maximum internal force occurs at the crown in the pipe cross section. therefore this internal force should be taken as design basis. To simplify computation. only the tensile stress caused by bending moment M will be considered for the action of both dead-weight and water weight. and its calculating equation is

$$\sigma = \frac{6M}{bh^2}$$

where:

h — thickness of pipe wall (cm);

M — bending moment caused by dead-weight of pipe body and water weight in the pipe (km-cm)

i.e. $M = \beta r_c G$

where:

r_c — mean radius of pipe (cm);

G — dead-weight of pipe body and water weight in the pipe per meter of pipe length (kg);

ß — coefficient of bending moment as shown in table 2.

(3) Tensile stress induced in pipe wall due to temperature difference between internal and external surfaces of pipe wall.

Because the pipe is filled with water and external surface of the pipe wall is exposed to the sunshine, the temperature difference between the internal and external surfaces of pipe wall is rather large. Consequently, it causes tensile stress at internal surface of pipe wall. This tensile stress is given as following expression:

$$\sigma_t = \frac{\alpha E_h}{2}\left[\mu\,(t_j - t_n) + \gamma\,(t_w - t_j)\right] - \delta_c$$

where:

α — linear expansion coefficient of concrete (1/°C)
E_h — modulus of elasticity of concrete under bending (kg/cm²)
t_n — temperature at internal surface of pipe wall °C
t_j — temperature at external surface of the pipe wall at the bottom (i.e. at the top of cushion) °C)
t_w — temperature at the external surface of pipe wall at the crown (°C)
δ_c — correction of the edge fiber stress, for $h \leqq 100$ mm. take $\delta_c = 0$; for $100\text{mm} < h \leqq 200$ mm, take

$$\delta_c = \frac{1}{6}\,\alpha E_h (t_w - t_n)$$

γ, μ — coefficient of bending moment as shown in Table 2.

Table 2 Coefficient of bending moment at the crown of pipe cross-section

Envelope angle of pipe cushion 2∅	Coefficient of bending moment		
	β	μ	γ
90°	0.077	1.20	0.826
135°	0.053	1.21	0.756

2. Computation of Circumferential Reinforcement

Circumferential prestressed wires of 2.5-5 mm in diameter are usually used. Its tensile controlling stress (namely, maximum permissible tensile stress during wire-winding operation) δ_k is given as follow:

For cold-drawn steel wire, $\delta_k = 0.65\, R_y^b$;

for high-strength steel wire $\delta_k = 0.7\, R_y^b$.

where R_y^b is standard strength of steel wire, (kg/cm²)

(1) Computation of prestress loss
a) Prestress loss due to relaxation of steel wire:
$\delta_{s1} = 0.07\,\delta_k$
b) Prestress loss due to contraction and creep of concrete
δ_{s2} which can be obtained by consulting Table 3.

Table 3 Prestress loss δ_{s2} (kg/cm^2)

$\frac{\delta_{hl}}{R'}$	0.1	0.2	0.3	0.4	0.5	0.6
δ_{s2}	200	300	400	500	600	900

In the table:

R' — Concrete cube strength of pipe core during wire-winding operation, take R' = 0.7 R (R is the concrete cube strength)

δ_{hl} — Pre-compressive stress subjected by pipe core concrete after wire-winding, calculated by following equation:

$$\delta_{hl} = \frac{A_y\delta_k}{bd}\ \mu_d\delta_h$$

where

A_y — total cross-sectional area of circumferential prestressed wire per meter of pipe length (cm^2)

μ_d — percentage of reinforcement of prestressed wire of pipe core, during design, an approximate value may be assumed at first, then revise it by steps in computation.

When $\frac{\delta_{hl}}{R'} > 0.6$, prestress loss will be larger, therefore, it is suggested to use high grade concrete for pipe core and to increase pipe wall thicnkess properly, in order to decrease the prestress loss δ_{s2}.

c) Prestress loss caused by compression of steel wire acted on concrete δ_{s3}.
For pipe diametre $\leq$ 3 m, $\delta_{s3} = 300$ kg/cm^2

d) Prestress loss due to temperature difference between internal and external surfaces of pipe wall δ_{s4}

$$\delta_{s4} = \alpha Eg\Delta t$$

where

α — linear expansion coefficient of steel wire (1/°C);

Eg — modulus of elasticity of steel wire (kg/cm^2);

Δt — temperature difference between internal and external surfaces of pipe wall.

overall loss of prestress is $\delta_s = \delta_{s1}+\delta_{s2}+\delta_{s3}+\delta_{s4}$ . . . . . . (4)

Consequently, effective prestress of prestressed wire is

$$\delta_y = \delta_k - \delta_s \qquad \ldots\ldots (5)$$

(2) Computation of pitch of prestressed wire

Since no crack should be allowed for the pipe in service period, the amount of prestressed wire should be determnied in accordance with crack-resistant requirement, thus the percentage of reinforcement of the wire is

$$\mu_d \geq [K_f(\frac{N}{bd} + \frac{6M}{bh^2} + \gamma_t) - \gamma_s R_f]\ \frac{1}{\delta_y} \qquad \ldots\ldots (6)$$

in which:

K_f — factor of safety for crack-resistant in design. taken as $K_f = 1.3$:
R_f — rupture strength of concrete (kg. cm²):
γ_1 — coefficient considering plastic deformation of concrete.

Total cross-sectional area of prestressed wire per meter of pipe length is

$$A_y = \mu_4 bd \qquad \ldots\ldots (7)$$

The pitch of steel wire S is

$$s = \frac{b f_y}{A_v} \qquad \ldots\ldots (8)$$

where

f_y — cross-sectional area for single steel wire (cm²).

The net pitch between steel wires should not be less than 5 mm, because smaller pitch will result in a pipe core with concrete not firmly adhesive to the protective layer which will be ready to fall off, and this will cause the steel wire exposed to air and will effect the service life due to rust corrosion. On the other hand, if the pitch is too larger, it will reduce the effect of prestress. Comparatively adequate pitch will be 15 — 25 mm.

(3) Computation of water pressure causing rupture of pipe body.

Although prestressed concrete pipe is subjected to the action of various loadings, but the internal water pressure is the major loading. Hence, the maximum internal water pressure which can be withstood by the pipe body is always taken as a main indication of pipe quality to be controlled during manufacturing process.

Equation for calculating internal water pressure causing rupture of pipe body P_k is

$$P_k = \frac{bdR_f + (\sigma_y + 300)Av}{\gamma_0 b} \qquad \ldots\ldots (9)$$

Definition of notes in the above equation are all the same as those described previously.

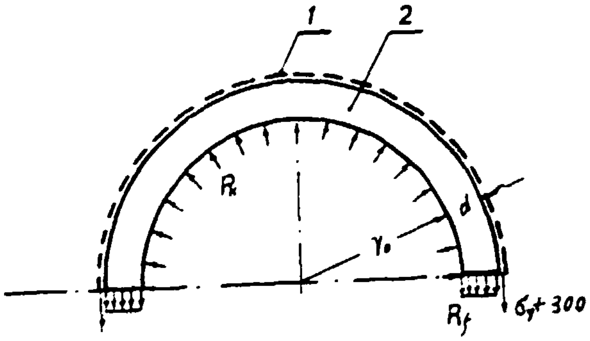

Fig. 3 Sketch Showing Forces Acting on pipe Body
1. prestressed wire; 2. pipe core

It can be observed by experiment that the water pressure causing rupture calculated by equation (9) was relatively close to the test results (as shown in Table 4).

C. Longitudinal Structure Computation of Pipe Body

Table 4 Comparison between Calculated Results and Test Results of Water Pressure Causing Rupture of Pipe Body

Diameter of Pipe (mm)	Concrete Pipe Core				Circumferential Prestressed Wire			Calculated Results of Rupture Pressure of Pipe (kg/cm²)	Test Results of Rupture Pressure (kg/cm²)
	Concrete Strength (kg/cm²)	Longitudinal Steel		Thickness (mm)	Stretching Stress Value (kg/cm²)	Diameter (mm)	Pitch (mm)		
		Diameter (mm)	No.						
800	640	4	36	70	4000	5	10	23.8	24
800	640	4	36	70	4000	5	10	23.8	24
400	640	4	18	35	3800	3.7	15	18.7	18

Notes :1. All steel wires listed in above table were cold-drawn steel wires;

2. Prestress loss used to caculate rupture pressure was taken as one half of the overall loss (because hydraulic pressure tests were conducted only several days after wire-winding of the pipe, and the prestress loss still did not cease).

In the course of manufacture and application, longitudinal tensile stresses are produced in pipe body due to various loadings acting on the pipe, and among these stresses the temporary longitudinal flexurral tensile stress induced in pipe core during wire-winding process is the maximu. In this way, the amount of longitudinal prestressed steel required can be designed on the basis of this tensile stress value.

1. Temporary longitudinal flexual stress induced during wire-winding operation

While wire is wound on the external surface of the pipe core wall. the wire-wound portion of concrete deforms due to compression of the wound wire. This causes the pipe to shrink diametrically as shown in Fig. 4

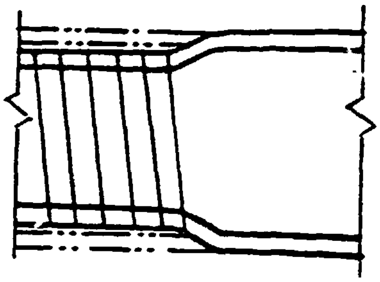

Fig. 4 Sketch Showing Longitudinal Deformation of pipe during wire-winding Process

Thus, a flexural tensile stress produce at the juncture between the portion of pipe which has been wire-wound and that not been wire-wound. According to theorectical analysis, this tensile stress is

$$\delta_2 = 0.275\,\mu_0\delta_k \qquad \ldots\ldots (10)$$

The maximum longitudinal flexural strain induced on the internal surface of pipe wall during wire-winding process had been measured with resistance strain gauge for two pipes, and the corresponding flexural tensile stresses had been calculated from the strain measurements. The results very closed with those calculated by Eq. (10) as shown in table 5.

Table 5 Comparison between Calculated Results of Longitudinal Temporary Flexural Tensile Stress and the Measured Results

Internal Diameter of Pipe Core (mm)	Thickness of Pipe Core wall (mm)	Circumferential Presstressed Wire		Circumferential Compressive Stress of Pipe Core δh (kg/cm^2)	Measured Long. Strain on Internal Surface of Pipe Core Wall εp	Longitudinal Stress $\delta = Eh\varepsilon p$ (kg/cm^2)	Calculated by Eq (10) δ_t 0.275μ.δk (kg/cm^2)
		Diameter (mm)	Pitch (mm)				
400	35	4	15	80	60×10^{-6}	20.4	22
800	70	5	10	110	80×10^{-6}	20.6	30.2

2. Determination of precompressive stress value applied on pipe core

In order to assure no circumferential crack appear on the pipe. the longitudinal prestressed compressive stress value acting on pipe core should be as follows

$$\delta_{zy} \geq \delta_z - 0.7 R_f \gamma_s \qquad \text{......} (11)$$

In the meantime. this longitudinal precompressive stress δ_{zy} should not be less than that specified in Table 6.

Table 6 Minimum Value of Longitudinal Prestressed Compressive Stress in Pipe Core

Nominal Internal Diameter of pipe (mm)	Longitudinal Precompressive Stress Value (kg cm^2)
200 — 600	30
700 — 900	25
1000 — 1300	20

3. Computation of Percentage of Reinforcement for Longi-Prestressed Steel

(1) Computation of Prestress Loss

(a) Prestress loss due to relaxation of steel wire

$$\delta_{s1} = 0.07\ \delta_k$$

(b) Prestress loss due to shrinkage and creep of concrete.

If longitudinal precompreesive stress applied to pipe core belongs to pre-tension method, the prestress loss due to shrinkage and creep of concrete δ_{s2} can be consulted from Table 7.

Table 7 Table 7 Prestress Loss for Pretension Method

$\frac{\delta hl}{R'}$	0.1	0.2	0.3	0.4	0.5
δ_{s2}	280	380	480	580	680

In the table:

δ_{hl} — Normal strees in concrete at the resultant acting point of prestressed steel. For simplification. it is possible to take approximately

$$\delta_{hl} = \delta_{zy}$$

(c) Prestress loss due to deformation of anchor block at the stretching end δ_{s3}

$$\delta_{s3} = \frac{\lambda}{l} Eg$$

where

λ — deformation of anchor block at stretching end (mm):

l — distance between stretching end and anchorage end (mm).

Total prestress loss of longitudinal steel is

$$\delta_s = \delta_{s1} \div \delta_{s2} - = \delta_{s5}$$

Then effective prestress of longitudinal steel is

$$\delta_y = \delta_k - \delta_s$$

(2) Computatioin of Longitudinal Reinforcement

Cross-sectional area of longitudinal prestressed steel required for pipe core is given by the expression:

$$A_y = \frac{\delta_{zy} A_h}{\delta_y} \quad \ldots\ldots (12)$$

where

A_h — circumferential cross-sectional area of pipe core (cm^2). Consequently, number of longitudinal prestressed steel required is

$$l_z = \frac{A_y}{f_y} \quad \ldots\ldots (13)$$

f_y — cross-sectional area of a single circumferential wire (cm^2)

III. The Manufacture Technology and Quality Examination of Prestress Concrete Pipes

In order to satisfy the design requirements in working capability, prestressed concrete pipes should possess sufficient resistance to permeability and cracking as well as sufficient durability. And these depend upon the quality control during the manufacture process. The resistance to permeability can be effected not only by material quality. mixing proportion. but also by the pipe core moulding technology. The application and control of longitudinal and circumferential prestress on the pipe and concrete strength of the pipe core are factors affecting the crack-resistance of pipes. Rust prevention of circumferential prestressed wire will reduce the durability of pipes to a considerable degree. Hence, the quality control and examination of prestressed concrete pipe in three-stage technology of centrifugal method which is universally adopted in our province is emphatically presented.

1. Control of Longitudinal Prestress

The longitudinal prestress of pipe is applied by prestretching the longitudinal steels which are then temporarily anchored on the pipe mould before the pipe core is moulded, so that the pipe core possibly obtains precompressive stress after moulding. Both electro-thermal stretching method and screw-rod stretching method are commonly used to apply longitudinal orestress as shown in Fig 7 and Fig 8. The Prestress value of longitudinal steel is controlled by elongation value of steel, namely the steel are stretched up to the specified elongation value which can be calculated by the following equation:

$$\Delta l = \frac{\delta_k \div 300}{E_s} l \quad \ldots\ldots (14)$$

in which:

Δl — elongation value of longitudinal steel (cm).

$\delta_.$ — controlled stretching stress of longitudinal steel (kg/cm^2),
$E_.$ — modulus of elasticity of steel (kg/cm^2).
l — distance between two anchorage points at the ends of longitudinal steel (cm).
300 — prestress loss caused by nonstraightness of steel, and plastic deformation of steel under conditions of high temperature and stress action (kg/cm^2).

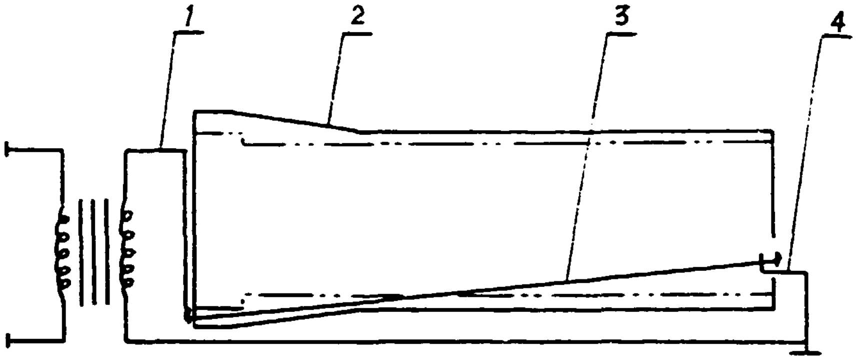

Fig. 5a Sketch Showing Connection of Three-phase Transformer Cable with Steel

1. secondary coil lead; 2. pipe mould; 3. longitudinal steel; 4. electro-thermal support bracket.

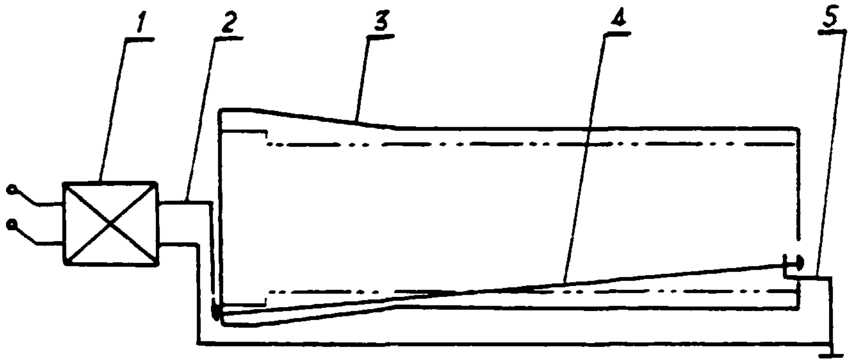

Fig. 5b Sketch Showing Connection of Arc Welding Machine with Electro-thermal Steel

1. arc welding machine; 2. secondary coil lead; 3. pipe mould; 4. longitudinal steel; 5. electro-thermal support bracket.

A wire-tensometer is used to measure the prestress value of the longitudinal steel.

2. Control of Quality of Aggregates

The quality requirements of sand and stone for prestressed concrete pipe are generally the same as those for high grade concrete. But, in order that the concrete can possess sufficient resistance to permeability, the clayey impurity and stone power in sand are required to be completely eliminated.

3. Control of Concrete Mixing Proportion

The mixing proportion of concrete used for pipe manufacture should be determined by test, and the proportion should not be changed at random during mixing, otherwise, permeability resistant property will certainly fluctuate. The so-called "control of of concrete mixing proportion" is mainly to control the water-cement ratio strictly. Because for concrete used in centrifugal moulding method, the remaining water-cement ratio generally equals 0.66-0.68 times the water-cement ratio before centrifugal moulding operation. in other words, the amount of water-cement ratio of concrete before centrifugal process is proportional to the remaining water-cement ratio of concrete after centrifugal moulding, therefo [illegible] is not allowed to add more water arbitrarily during concrete mixing.

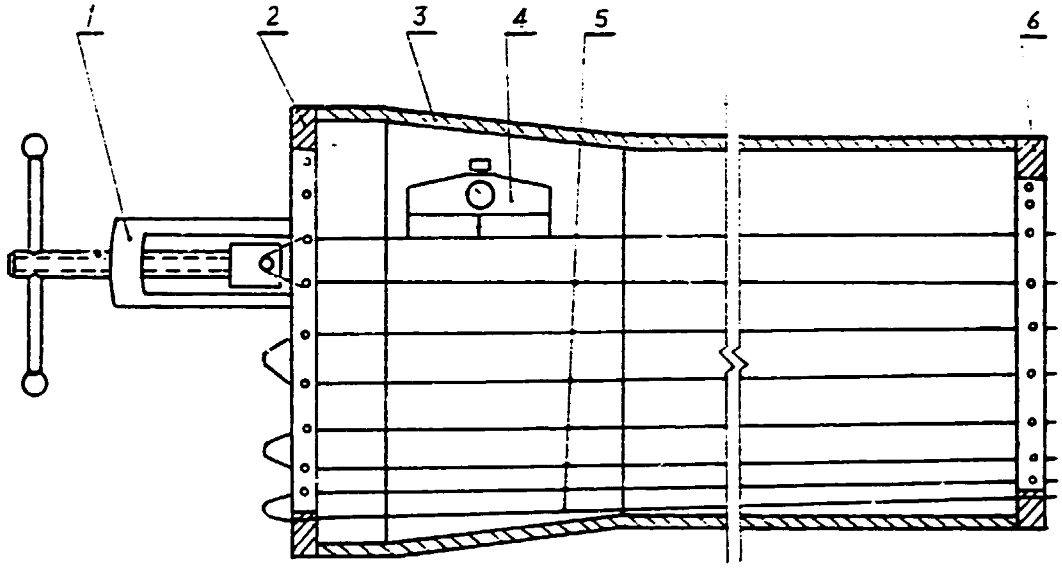

Fig. 6 Sketch Showing Longitudinal Steel Stretching with Screw-rod Stretching Machine

1. screw-rod stretching device; 2. socket anchorage capstan; 3. pipe mould; 4. wire tensometer; 5. longitudinal prestressed steel; 6. spigot anchorage capstan.

4. Control of Centrifugal Technology

The centrifugal process is divided into three-stages, namely, slow speed, intermediate speed, high speed. and the control of centrifugal technology means the adjustment of magnitude of speed and duration of time of these three stages.

(1) Slow Speed Control

Slow speed rotation is the first step in centrifugal technology, the aim of which is to provide facility for material feeding and to made concrete material adhere firmly to the pipe mould wall uniformly. For this purpose, the centrifugal force produced by the rotating speed should be larger than dead-weight of the concrete material. i.e.

$$m\omega^2 r > mg$$

Where

m — mass of concrete (gm. sec cm^{-2})

ω — rotation angular velocity

$$\omega = \frac{2\pi r}{60} (1/\text{sec.})$$

r — rotation radius. namely. external radius of pipe core (cm).

g — gravity acceleration. g = 981 cm sec^2.

n — rotating speed of pipe mould (r.p.m.)

Consequently. following expression for slow speed can be obtained

$$n > \frac{300}{\sqrt{r}}$$

Through practice. slow speed control is generally taken as 1.5 — 1.6 times the theoretical rotation speed. i.e.

$$n = (1.5\sim1.6)\ \frac{300}{\sqrt{r}} \qquad \ldots\ldots (15)$$

The control of the duration of time required for slow speed centrifuge depends upon the degree of uniformity of material distribution on the pipe mould wall, and it will be longer for larger pipe diameter. and shorter for smaller one. It generally keeps between 5 to 15 minutes.

(2) Intermediate speed centrifuge is a transitional stage from slow speed to high speed centrifuge and this transitional speed should be raised uniformly. Because water-cement ratio of concrete in centrifugal technology is relatively low, the flowability of concrete mixture is relatively small. If rotation speed was raised to high speed suddenly. abrupt dis-placement of material would be certainly produced, and consequently cause nonuniformity of pipe wall thickness. Furthermore, abrupt rise of speed will readily cause skipping of the pipe mould. thus intensify the segregation of material. Therefore. the principle of intermediate speed control must be raising gently from slow speed to high speed. The revolution per minute and the duration of time required should be determined by practical observation. In general, the duration of time never exceeds 10 minutes.

(3) High speed control

High speed centrifuge is the final stage of centrifugal technology, and also an important stage at which the concrete will attain its maximum density. According to theorectical derivation. the expression for centrifugal pressure will be

$$F = \frac{r_h \pi^2 n^2}{2700g} \left(r^2 - \frac{r_o{}^3}{r}\right) \qquad \ldots\ldots (16)$$

in which

F . — centrifugal pressure of core concrete acting on pipe mould (kg cm^2);

r_h — unit weight of concrete (kg cm^3);

n — rotation speed of pipe mould (r.p.m.);

r_o & r — internal and external radii of pipe respectively (cm).

From Eq. (16) it can be known, when dimensions of the pipe are constant. the larger the rotation speed in high speed centrifuge, the larger the centrifugal compressive force produced. Hence to raise centrifugal rotation speed is an important means to increase the strength and permeability-resistant capability of the pipe. To choose the rotation speed in high speed centrifuge. a rotation speed corresponding to a centrifugal compressive stress which reaches 0.8 — 1.0 kg/cm^2 will be considered as the best. But the best rotation speed can often hardly attain owing to the poor rigidity of pipe mould which is usually made by hand manual with steel plate 3-6 mm in thickness. and the centrifugal pressure which the pipe mould can withstand alwayes does not exceed 0.5 kg/cm^2. On the basis of production practice. when a prestressed concrete pipe with an internal diameter of 1.250 mm was manufactured. a centrifugal pressure between 0.73-0.75 kg/cm^2 enabled permeability-resistance of the pipe to reach 34 kg/cm^2 or above. so that it could be used safely in a high head hydro-electric plant with a design internal water pressure of 21.2 kg/cm^2. Consequently. control of high speed centrifuge should be determined according to the diameter of pipe and the magnitude of permeability resistant pressure required. Generally speaking. centrifugal pressure acting upon the pipe mould may be chosen in the range of 0.4 — 0.75 kg/cm^2. Use upper limit for higher permeability-resistant pressure required and lower limit for lower one.

The control of duration of time for high speed centrifuge should be determined by the degrees of drainage and density of concrete. sometimes even be determined by water pressure test.

(4) Control of operation technique

On the basis of the feature of segregation due to centrifugal process. the impermeability of concrete pipe core mainly relies on the mortar layer plus the cement layer. The two together are named permeability-preventive layer. the thickness of this layer only takes 1/4 of pipe thickness. If a method adopted is that both feed and cenrtifugal processes are done layer by layer, so that multiple permeability preventive layers are formed in the pipe wall. then permeability resistance can be markedly advanecd.

In general. the feed-and-centrifuge process can be proceeded in 2-4 separate times depending on the difference in both thickness of pipe wall and diameter of pipe.

5. Control of Circumferential Prestress

The circumferential prestress in pipe is obtained when the prestressed wire is wound around the external surface of pipe core wall. Weight-balanced tension type wire-winding machine is extensively adopted in our province to wind circumferential prestressed wire. The principle of wire-winding is shown in Fig. 7. The wire is subjected to a tension which equals half the weight of weight block, and prestress value of the circumferential wire can be controlled by adjusting the weight of the weight block to be hung, which may be calculated by the following equation:

$$W = 2\delta_k f_y \qquad \ldots\ldots (17)$$

in which

W — weight of the weight block (kg),

δ_k — controlled tensile strees of circumferential wire (kg/cm^2).

f_y — cross-sectional area of a single circumferential wire (cm^2).

The circumferential prestressed wire is wound onto the pipe core through the guide pulling mounted on the gantry which is moving forward when the pipe core rotates. The pitch of the wire to be wound can be controlled by adjusting the moving velocity of the gantry.

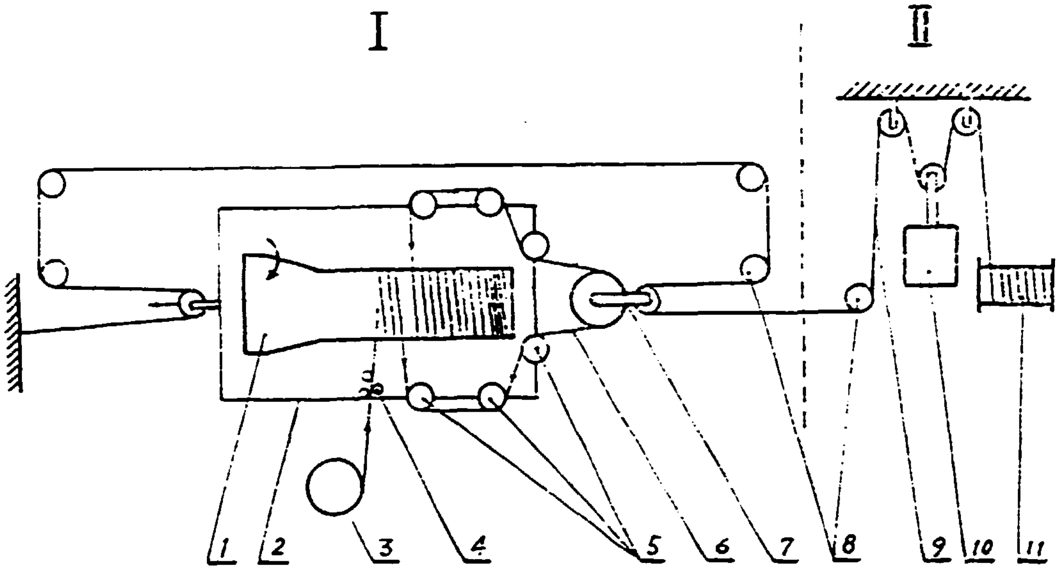

Fig. 7 Sketch Illustrating the Working Principle of Weight-balanced Tension Type Wire-winding Machine

I. wire-winding system II. balancing weight system
1. pipe core, 2. gantry, 3. steel wire capstan, 4. wire-fastening and guide device, 5. prestressed wire guide pulley, 6. prestressed wire, 7. tension transmitting device, 8. steel cable guide pulley, 9. steel cable, 10. weight block, 11. winch.

If circumferential hair cracking appeared on the internal surface of pipe core wall after wire winding, it is necessary to examine whether structure design of the pipe is reasonable, whether prestress on longitudinal steel is sufficiently applied during pipe manufacture process, and whether the pipe core has reached its specified strength during wire-winding operation. Then corresponding measure should be taken to improve. This sort of circumferential hair cracking can be repaired with epoxy-resin.

6. Protection of Circumferential prestressed Wire

The service life of prestressed concrete pipe is rather long. But circumferential prestressed wire will break off after rust corosion and induce failure of the pipe. In general. a cement mortar layer. 15-20 mm in thickness. was made on pipe surface by machanical means or manually as a protective coating for circumferental prestressed wire. In order to protect circumferential prestressed wire, at present, a method employed is to apply a rust- preventative coating on the wire. The practical method of work is to install a rust preventative material container on one side of the gantry of wire winding machine, as shown in Fig. 8. When the wire passes through the container. a rust-preventative coat is automatically applied on its surface just before winding onto the pipe core. Then, when the cement mortar protective coating fails, a rust-preventative coating still remains on steel wire itself.

7. Hylraulic Pressure Test

The permeability-resistance and crack-resistance must be examined by passing through hydraulic pressure test. The equipment used in conducting hydraulic test is fully-water-fill type hydraulic pressure testing machine, but for pipes with larger diameter and subjected to higher pressure, an internal sleeve type hydraulic pressure testing machine may be more convenient, ts shown in Fig. 9. Because during hydraulic pressure examination, the lattter type can greatly reduce the total thrust of water pressure against bulkhead at both pipe ends, so that water sealing between bulkhead and pipe becomes not so difficult.

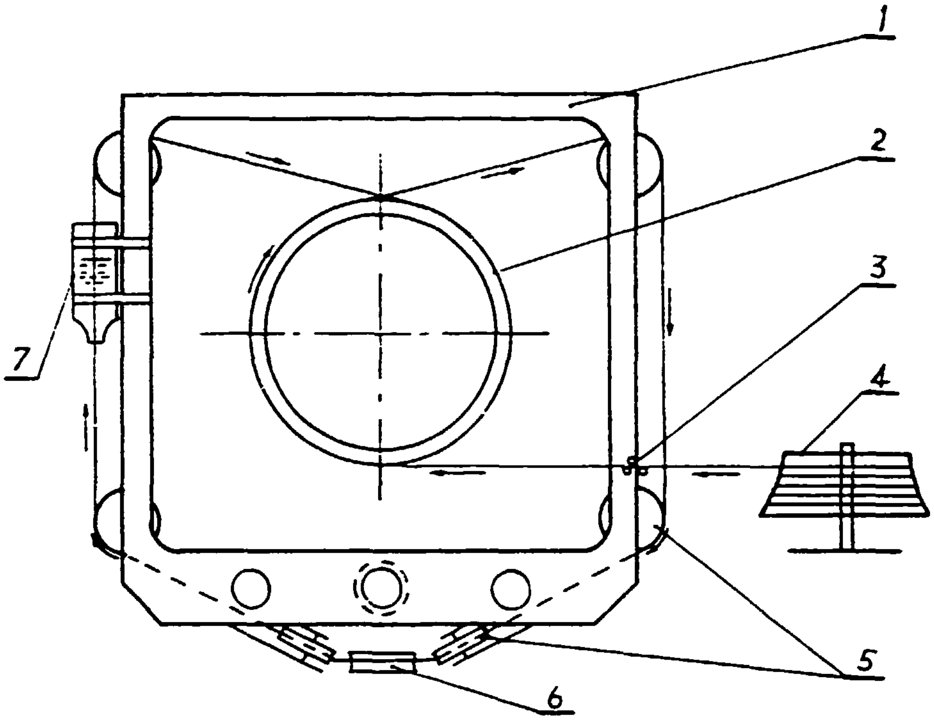

Fig. 8 Sketch Illustrating Automatic Application of Rust-preventative on prestressed Wire

1. gantry, 2. pipe core, 3. wire-fastening-and-guide device. 4. steel wire capstan, 5. steel wire guide pulley, 6. tension transmitting device, 7. rust-preventative material container.

Because prestressed concrete pipes used in hydroelectric station are always laid along the hill slope in open air and do not subjected to earth pressure and other live load acting on ground surface, thus the pressure used in hydraulic examination is always taken as 1.3 times the sum of hydrostatic pressure and water hammer pressure increment, i.e. 1.3 time the design internal water pressure. If percolation and crack do not appear in the pipe under such water pressure condition, it will be considered as qualified. All pipes should be installed and employed only after passing through both permeability-resistance and crack-resistance examinations.

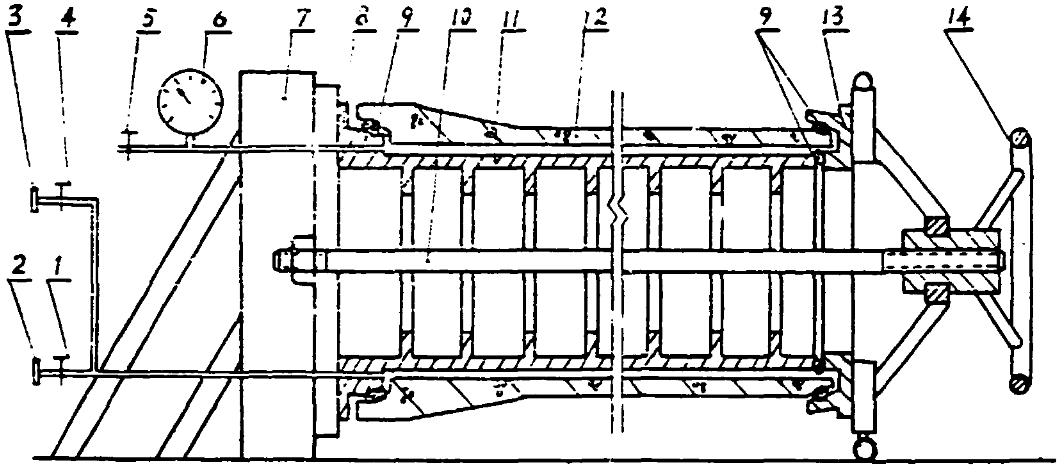

Fig. 9 Sketch Illustrating Internal-sleeve Type Hydraulic Pressure Testing Machine

1. water intake valve for pressure test, 2. connected to electrical pressure test pump, 3. connected to water pump, 4. water filling valve, 5. air release valve, 6. pressure gauge, 7. machine support, 8. stationary bulkhead, 9. water-sealing rubber ring, 10. tension rod, 11. steel sleeve, 12. prestressed concrete, 13. movable bulkhead, 14. hand wheel.

Conclusion

Through practice more than ten years,it has been shown that prestressed concrete pipes possess higher crack-resistance and better permeability-resistance. The application of this sort of pipe in hydro-electric station under 200 meter water head has been verified to be feasible and safe. Prestressed concrete pipes under 1,300 mm in diameter can be manufactured with comparatively simple equipment in-situ or in the plant.