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पूर्वप्रबलित कंक्रीट (पीएससी) के निर्माण में गुणवत्ता नियंत्रण के लिए दिशा निर्देश

GUIDELINES FOR QUALITY CONTROL IN PRESTRESSED CONCRETE (PSC) CONSTRUCTION

केमटेक/2017/सि/क्यूसी-पीएससी/1.0
CAMTECH/2017/C/QC-PSC/1.0

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अअमासं RDSO
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प्राक्कथन

सिविल निर्माण का सबसे महत्वपूर्ण पहलू इसकी गुणवत्ता है , जिससे समझौता नहीं किया जाना चाहिए। कंक्रीट डिजाइन और निर्माण में गुणवत्ता के पहलुओं को प्राप्त करने के लिए, मूल्यांकन के लिए विनिर्देशों (मानकों) और उचित परीक्षण विधियों को पूरा करना चाहिए।

व्यापक रूप से स्वी कृत पूर्वप्रबलित कंक्रीट एक उच्च सामर्थ्य वाली कंक्रीट है, जो प्रबलित कंक्रीट जैसे अन्य निर्माण की तुलना में अधिक तकनीकी लाभ प्रदान करता है। इतनी जागरूकता के साथ, यह आवश्यक है कि सिविल इंजीनियरों को नवीनतम विकास, नई तकनीकी प्रगति और भविष्य की संभावनाओं के प्रति अधिक जागरूक होना चाहिए।

यह आशा की जाती है कि कैमटेक द्वारा तैयार पुस्तिका सिविल संरचनाओं के निर्माण एवं रखरखाव की गतिविधियों में लगे भारतीय रेलवे के इंजीनियरिंग कर्मियों के लिए काफी मददगार होगी।

केमटेक / ग्वालियर ***(ए. आर. तुपे)***

मार्च 30, 2017 ***कार्यकारी निदेशक***

FOREWORD

The most important aspect of civil construction is its quality, which should not be compromised. To achieve the quality aspects in concrete design and construction, it should meet the specifications (standards) and appropriate test methods for evaluation.

The widely accepted prestressed concrete is a high strength concrete, which offers great technical advantages in comparison with other forms of construction, such as reinforced concrete. With so much of awareness, there is a need that civil engineers should be more aware with the latest developments, new technological advances and future prospects.

It is expected that the handbook prepared by CAMTECH will be quite helpful to the engineering personnel of Indian Railways engaged in construction and maintenance activities of civil structures.

CAMTECH/Gwalior ***(A.R. Tupe)***
March 30, 2017 ***Executive Director***

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पूर्वप्रबलित कंक्रीट ने आरंभ से ही दुनिया भर में प्रमुख अनुप्रयोगों में पुलों, पानी के टैंक, पोल, फ्लैट स्लैब, रेलवे स्लीपरों, बांधों तथा वाणिज्यिक भवनों, स्कूल ऑडिटोरियम, व्यायामशालाओं, कैफेटेरिया, इत्यादि के निर्माण में महत्वपूर्ण स्थान प्राप्त किया है।

'**पूर्वप्रबलित कंक्रीट (पीएससी) निर्माण में गुणवत्ता नियंत्रण के लिए दिशानिर्देश**' विषय पर यह पुस्तिका जानकारी प्रसारित करने के उद्देश्य से तैयार की गई है जिससे कि पीएससी निर्माण में गुणवत्ता आश्वासन सुनिश्चित करने और पूर्वप्रबलन प्रक्रिया की मूल अवधारणा से भारतीय रेल के इंजीनियरों को परिचित कराया जा सके।

यह पुस्तिका संवैधानिक नहीं है तथा सामग्री केवल ज्ञान प्रसार के उद्देश्य के लिए है। किसी न किसी रूप में अधिकांश डेटा एवं जानकारी, उपलब्ध साहित्य तथा इंटरनेट खोज पर आधारित है। अधिक गहराई से जानकारी / ज्ञान के लिए , विषय पर उपलब्ध प्रासंगिक विस्तृत साहित्य , भारतीय मानक ब्यूरो संहिताओं , आदि को संदर्भ रूप में देखा जा सकता है।

इस पुस्तिका के और अधिक सुधार हेतु हम अपने पाठकों के सुझावों का स्वागत करते हैं।

केमटेक / ग्वालियर ***(डी. के. गुप्ता)***

मार्च 29, 2017 ***संयुक्त निदेशक***

PREFACE

Prestressed concrete construction has gained importance since its inception and worldwide acceptance to the major applications in bridges, water tanks, poles, flat slabs, railway sleepers, dams and also in commercial buildings, school auditoriums, gymnasiums, cafeterias, etc.

This handbook on **'Guidelines for Quality Control in Prestressed Concrete (PSC) Construction'** is prepared with the objective to disseminate the knowledge to the engineers of Indian Railways to be acquainted with the basic concept of prestressing process and to ensure Quality Assurance in PSC Construction.

This handbook is not statutory and contents are only for the purpose of knowledge dissemination. Most of the data & information in some form or the other are based on literature available and internet search. For more in-depth information / knowledge, the relevant detailed literature, BIS Codes, etc. available on the subject may be referred to.

We welcome any suggestions from our readers for further improvement of this handbook.

CAMTECH/Gwalior ***(D.K. Gupta)***
March 29, 2017 ***Joint Director/Civil***

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अध्याय / Chapter – 1

निर्माण में गुणवत्ता नियंत्रण / Quality Control in Construction

Quality means excellence, which can be defined as the totality of features and characteristics of a product or services that bear on its ability to satisfy stated or implied needs.

In concrete design and construction, quality means compliance with standards (code of practice) to meet the requirements by:

(i) acceptable materials of construction outlining the various tests of acceptance
(ii) design criteria practical rules and sound engineering practices for guiding the designers in arriving at appropriate structural solutions
(iii) *workmanship and other aspects of construction* which ensure that the design intents are realized in actual construction

Quality assurance in construction activities guides the use of correct structural design, specifications and proper materials ensuring that the quality of workmanship by the contractor /sub-contractor is achieved. Quality assurance is the primary responsibility of the quality control staff.

Quality control is the part of quality management that focuses on fulfilling the quality requirements. Quality control –

(i) means rational use of resources
(ii) produces appropriate mixing, proper compaction, correct placement and adequate curing
(iii) prevents temptation of over design
(iv) ensures strict monitoring of every stage of concrete production and rectification of faults
(v) reduces maintenance costs

It should be remembered that the quality is closely related to accidents and safety. Poor quality construction invites accidents, while construction is going on even later on. Therefore, it is important that everyone involved with the *concrete construction* should ensure the quality construction.

Also, consistency is another very important dimension of quality and variability is an indicator of poor quality. While using new materials, it must be assured that the quality of construction product (i.e. structure which is built) whether it is a building or a bridge or a dam should not be compromised.

The following activities at a frequency adequate to meet the specific quality objectives in prestressed concrete construction should be ensured:

(i) Procedures for batching, mixing, placing, consolidating, curing, and finishing of concrete should be verified.
(ii) Mix designs should be prepared and evaluated.

(iii) Proper fabrication and placement of reinforcement and cast-in items should be verified.
(iv) Finished products for conformance with the shop drawings and other project requirements, such as approved samples, when required should be inspected.
(v) Forms should be inspected and verified for the accuracy of dimensions and conditions.
(vi) Procedures for concrete repair, handling, storing, and loading of finished products should be verified.
(vii) Tensioning operations to ensure conformance with specified procedures should be inspected.
(viii) Complete quality control records should be prepared and maintained.

Quality assurance is the primary responsibility of the quality control staff. Production personnel should be involved in assuring quality and communicate closely with the quality control staff. Quality control personnel shall be responsible for ensuring that the following activities at a frequency adequate to meet the following specific quality objectives:

1. Inspecting and verifying the accuracy of dimensions and conditions of forms.
2. Verifying procedures for batching, mixing, placing, consolidating, curing, and finishing concrete.
3. Verifying procedures for concrete repair, handling, storing, and loading of finished products.
4. Verifying the proper fabrication and placement of reinforcement and cast-in items.
5. Inspecting tensioning operations to ensure conformance with specified procedures.
6. Preparing and evaluating mix designs.
7. Inspecting finished products for conformance with the shop drawings and other project requirements, such as approved samples, when required.
8. Preparing and maintaining complete quality control records.

***

अध्याय / Chapter – 2

शब्दावली / Terminology

The following terms defined in relevant Indian standards are commonly used in prestressed concrete.

- **Anchorage Device** — In post-tensioning, the hardware used for transferring the post-tensioning force from the tendon to the concrete in anchorage zone.

- **Bonded Member** — A prestressed concrete in which tendons are bonded to the concrete either directly or through grouting.

- **Bonded Post-tensioning** — Post-tensioned construction in which the annular spaces around the tendons are grouted after stressing, thereby bonding the tendon to the concrete section.

- **Bonded tendon**— When there is adequate bond between the prestressing tendon and concrete, it is called a bonded tendon. Pre-tensioned and grouted post-tensioned tendons are bonded tendons.

- **Breaking Load** – The maximum load reached in a tensile test on the strand.

- **Cable** — A group of wires or bars or strands or rods.

- **Characteristic Load** — Load which has 95 percent probability of not being exceeded during the life of the structure.

- **Characteristic Strength** — Strength of material below which not more than 5 percent of the test results are expected to fall.

- **Coil or Reel** – One continuous length of strand in the form of a coil or reel.

- **Column or Strut** — A compression member, the effective length of which exceeds three times the least lateral dimension.

- **Creep** — Time dependent deformation due to sustained load.

- **Creep Coefficient** — The ratio of creep strain to elastic strain in concrete.

- **Elongation –** The increase in length of a tensile test piece under stress. In case of strands, the elongation is measured immediately prior to fracture of any of the component wires and is expressed as a percentage of the original gauge length of a standard test piece.

- **Final Prestress** — The stress which exists after substantially all losses have occurred.

- **Final Tension** — The tension in the prestressing tendon corresponding to the state of the final prestress.

- **Initial Prestress** — The prestress in the concrete at transfer.

- **Initial Tension** — The maximum stress induced in the prestressing tendon at the time of the stressing operation.

- **Length of Lay –** Length of lay is the distance measured along a straight line parallel to the strand forming one completed spiral of a wire around the strand.

- **Parcel –** Any quantity of finished strand presented for examination and test at any one time.

- **Post-tensioning** — A method of prestressing concrete in which prestressing steel is tensioned against the hardened concrete. Here the prestress is imparted to concrete through bearing.

- **Pre-tensioning** — A method of prestressing concrete in which the tendons are tensioned before concreting. In this method, prestress is imparted to concrete through bond between steel and concrete.

- **Production Length –** The maximum length of strand which can be manufactured without welds being made after drawing in any of its component wire.

- **Proof Load –** The load which produces a residual strain of 0.2 percent of the original gauge length (non-proportional elongation).

- **Relaxation** — Time dependent increase in steel strain at constant stress.

- **Strand –** A group of wires laid helically over a central-core wire. A seven-wire strand would thus consist of six outer wires laid over a single wire core.

- **Seven Wire Strand –** Any length of finished material which comprises six wires spun together in helical form around a central wire.

- **Three wire Strand –** Any length of finished material which comprises three wires spun together in helical form.

- **Two Wire Strand –** Any length of finished material which comprises two wires spun together in helical form.

- **Sheathing** — A material encasing a prestressing tendon to prevent bonding the tendon with the surrounding concrete during concrete placement to provide corrosion protection.

- **Short Column** — A column, the effective length of which does not exceed 12 times the least lateral dimension.

- **Slender Column** — A column, the effective length of which exceeds 12 times the least lateral dimension.

- **Shrinkage Loss** — The loss of stress in the prestressing steel resulting from the shrinkage of the concrete.

- **Stress at Transfer** — The stress in both the prestressing tendon and the concrete at the stage when the prestressing tendon is released from the prestressing mechanism.

- **Tendon** — A steel element, such as a wire, cable, bar, rod or strand, or a bundle of such elements used to impart prestress to concrete when the element is tensioned.

- **Transfer** — The act of transferring the stress in prestressing tendons from the jacks or pre-tensioning bed to the concrete member.

- **Transmission Length** — The distance required at the end of a pre-tensioned tendon for developing the maximum tendon stress by bond.

- **Un-bonded tendon –** A tendon in which the prestressing steel (strand) is prevented from bonding to the concrete. When un-bonded tendons are used, prestressing force is permanently transferred to the concrete only by the anchorage.

- **Wedges –** Pieces of tapered metal with teeth that bite into the prestressing steel (strand) during transfer of the prestressing force. The teeth are beveled to assure gradual development of the tendon force over the length of the wedge. These are standard internal portions of a strand chuck assembly.

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अध्याय / Chapter – 3

पूर्वप्रबलित कंक्रीट / Prestressed Concrete

3.1 पूर्वप्रबलन/ Prestressing

Prestressing can be defined as the application of a predetermined force or moment to a structural member in such a manner that the combined internal stresses in the member resulting from this force or moment and from any anticipated condition of external loading will be confined within specific limits.

3.2 पूर्वप्रबलित कंक्रीट के लाभ / Advantages of Prestressed Concrete

Prestressed concrete offers great technical advantages in comparison with other forms of construction, such as reinforced concrete and steel.

i) It is free of cracks under service loads and enables the entire section to take part in resisting moments.
ii) It eliminates corrosion of steel when the structure is exposed to weather.
iii) In prestressed concrete structures sections are much smaller than those in reinforced concrete structures because dead load moments are neutralized by the prestressing moments and shear stresses are reduced.
iv) The reduced self weight of the structure further saves the cost of foundation.
v) It has high ability to resist impact.
vi) It has high fatigue resistance.
vii) It has high live load carrying capacity.
viii) It is possible to assemble precast prestressed elements thus saving cost of shuttering and centering, and time besides maintaining a high quality control.
ix) Extremely useful in the construction of liquid retaining structures and nuclear power reactors where absolutely no leakage is acceptable.
x) This technique is of great value in railway sleepers, large span bridges and large span roofs.

3.3 पूर्वप्रबलित कंक्रीट की आवश्यकताएँ / Requirements of Prestressed Concrete

The basic requirements of prestressed concrete are mainly strength and durability of concrete. Following are the requirements of prestressed concrete in terms of properties of various materials used as under.

- **A high value of strength – compressive, tensile and shear strengths:** These properties of concrete may be associated with a high value of Young's modulus of elasticity, greater density, etc.
- **Low early shrinkage and small creep deformations**: These properties of concrete are associated with the mix of concrete and are influenced by the richness of mix and water-cement ratio.

- **Durability of concrete:** This property is influenced by the quality of concrete and depends on its resistance to deterioration and the environmental conditions around concrete.

3.4 उच्च सामर्थ्य कंक्रीट और स्टील की ज़रूरत / Need for High Strength Concrete and Steel

- *High strength concrete*: High strength concrete is necessary in prestressed concrete since the material offers high resistance in tension, shear, bond and bearing.

  a) In the zone of anchorages, the bearing stresses being higher, *high strength concrete* is invariably preferred to minimize costs.
  b) *High strength concrete* is less liable to shrinkage cracks, and has a higher modulus of elasticity and smaller ultimate creep strain, resulting in a smaller loss of prestress in steel.
  c) The use of *high strength concrete* results in a reduction in the cross sectional dimensions of prestressed concrete structural elements.
  d) With reduced dead weight of the material, longer spans become technically and economically practicable.

- *High strength steel*: The normal loss of stress in steel is generally about 100 to 240 N/mm^2 and it is apparent that if this loss of stress is to be a small portion of the initial stress, the stress in steel in the initial stages must be very high, about 1200 to 2000 N/mm^2. These high stress ranges are possible only with the use of *high strength steel*.

3.5 कंक्रीट एवं इसके अवयव / Concrete and its components

The concrete is a homogeneous mixture of Portland cement, aggregate, water and admixture (if permitted to use). The concrete's tensile strength is only 8 to 14 percent of its compressive strength. This is the weakness of concrete, which can be offset by reinforcing or prestressing concrete with steel.

3.5.1 सीमेंट / Cement

It is the most important and costliest ingredient of concrete. In general, cement is described as a material used to bind the mineral fragments called aggregates. The cement paste acts as glue which makes a cohesive mass with all the aggregates.

Generally, following types of cement are used in concrete making:

i) OPC 33 grade (IS 269:1979): Grade 33 ordinary Portland cement may be used for most of the works. It has a 28 days' strength of 33 MPa (33 kg/cm^2).
ii) OPC 43 grade (IS 8112:1987): Grade 43 ordinary Portland cement can be used in works where grade 33 is used and where the spaces are longer.
iii) OPC 53 grade (IS 12269:1992): For higher strength requirements of works or for specialized works, such as, prestressed concrete work, higher grades of cement such as 53

grade ordinary Portland cement may be used.*OPC 53-S Grade cement is used in manufacture of PSC Sleepers for Indian Railways*.

Field test for cement

a) Check the date of manufacture of cement lots as aging reduces cement strength (Table– 1).
b) Open the bag and take a good look at the cement, there should be no visible lump.
c) Thrust your hand into a cement bag, it must give you cool feeling.
d) Take a pinch of cement and feel if between the fingers it should give you a smooth and not gritty feeling.
e) Take a handful of cement and throw it on the water in a bucket. The particles should float before they sink.

Table – 1 Reduction of Cement Strength due to Age

Period of storage (months)	*Approx. relative strength w.ref.t. 28 days strength*
Fresh	100%
3	80%
6	70%
12	60%
24	50%

Storage of Cement

One must understand that cement is hygroscopic in nature and loses its cementaceous properties with time and exposure to moisture. Therefore, certain precautions (Table – 2) are necessary in storage of cement.

- Do not pile bags to a height higher than 15 bags.

  As per IS 4082:1996, the height of stack shall not be more than 10 bags to prevent the possibility of lumping up under pressure. The width of the stack shall be not more than four bags length or 3 metres.

- During monsoon, cover the stacks with 700 gauge polythene sheet.
- Different types of cements shall be stacked and stored separately.
- Cement bags shall be stacked off the floor on wooden planks in such a way as to keep about 150 mm to 200 mm clear above the floor.
- In case of a wagon/truck load of up to 25 tonne, the overall tolerance on net quantity of cement shall be 0 to 0.5 percent.

Table – 2 Necessary Precautions during Storage of Cement

Cement godown	i) It should be airtight ii) It should be moisture proof
Stack the cement bags	i) on raised plinth/platform ii) in separate piles as received with identification tags indicating- • Cement company • Cement type • Date of manufacture • Grade of cement • Batch number iii) with 0.6 m clearance between adjacent stacks & outer walls

Note:

1. Test certificate from manufacture for each batch should be kept in records.
2. Cement older than 3 months should normally not be used for PSC works unless the quality is confirmed by tests.

Properties required for different cement

Characteristics	OPC		
	Grade 33 (IS 269)	**Grade 43 (IS 8112)**	**Grade 53 (IS 12269)**
Physical Requirements:			
i) Fineness specific surface, m^2/kg, *Min*	225	225	225
IS 4031 (Part 2)			370(53-S Grade)*
ii) Soundness: IS 4031 (Part 3)			
a) By Le Chatelier method, mm, *Max*	10	10	10
b) By autoclave test method, percent, *Max*	0.8	0.8	0.8
iii) Setting time: IS 4031 (Part 5)			
a) Initial, min, *Min*	30	30	30
			60(53-S Grade)*
b) Final, min, *Max*	600	600	600
iv) Compressive strength, MPa			
IS 4031 (Part 6)			
a) 72 ± 1 h, *Min*	16	23	27
b) 168 ± 2 h, *Min*	22	33	37
		37.5(43-S Grade)	37.5(53-S Grade)*
c) 672 ± 4 h, *Min*	33	43	53
Max	48	58	-
* 53-S Grade cement is used in manufacture of PSC Sleepers for Indian Railways.			

53-S Grade cement conforming to IS: 12269 -1987 (Re-affirmed 2013) shall be used in manufacture of PSC Sleepers for Indian Railways. [Serial No. T-39 (Fifth Revision –February 2016), RDSO, Lucknow]

Referring to IS: 12269 – 2013

- **The Para of Foreword** reads as "Specific requirements of ordinary Portland cement for manufacture of railway sleepers to be designated as 53-S grade are given in 5.2, Table 3 and 10.1. To differentiate it with normal grade, '53-S grade' shall be marked on the bags/packages for such cement in place of '53 grade'."

- **Para 5.2**: Cement used for railway sleepers shall additionally satisfy the following chemical/mineralogical requirements and shall be designated as 53-S grade:

  a) Magnesia, percent by mass, Max 5.0
  b) Tricalcium aluminate content, percent by mass, Max 10.0
  c) Tricalcium silicate, percent by mass, Min 45.0

  Note– The tricalcium aluminate content (C_3A) and tricalcium silicate content (C_3S) are calculated by the formula:

  $$C_3A = 2.65\ (Al_2O_3) – 1.69\ (Fe_2O_3)$$

$$C_3S = 4.07\ (CaO) - 7.60\ (SiO_2) - 6.72\ (Al_2O_3) - 1.43\ (Fe_2O_3) - 2.85\ (SO_3)$$

Where, each symbol in brackets refers to the percent (by mass of total cement) of the oxide, excluding any contained in insoluble residue (i.e. percent by mass, Max 4.0).

- **Para 10.1**: Each bag of cement shall be legibly and indelibly marked with the following:

a) Manufacturer's name and his registered trademark;
b) The words 'Ordinary Portland Cement, 53 Grade' or 'Ordinary Portland Cement, 53-S Grade', whichever is applicable;
c) Net quantity, in kg;
d) The words 'Use no Hooks';
e) Batch/control unit number in terms of week, month and year of packing;
f) Address of the manufacturer; and
g) Type and percentage of performance improver(s) added, in case of addition of performance improvers.

3.5.2 एग्रीगेट / Aggregates

The aggregate is the matrix or principal structure consisting of relatively inert fine and course materials. Coarse aggregate provides bulk to the concrete to increase density of resulting mix, while fine aggregate is to assist in producing workability and uniformity in mixture. This also assists the cement paste to hold the coarse aggregate particles in suspension. This action promotes plasticity in the mixture and prevents the segregation of the paste and coarse aggregate. The aggregate influence is extremely important.

- All aggregates shall comply with the requirements of IS 383-1970 (Re-affirmed 2002).
- Aggregates shall consist of naturally occurring (crushed or uncrushed) stones, gravel and sand or combination thereof.
- Aggregates shall be hard, strong, dense, durable, clear and free from veins and adherent coating; and free from injurious amounts of disintegrated pieces, alkali, vegetable matter and other deleterious substances.
- Aggregates which are chemically reactive with alkalies of cement are harmful as cracking of concrete may take place.
- The nominal maximum size of coarse aggregate should be as large as possible within the limits specified but in no case greater than one-fourth of the minimum thickness of the member, provided that the concrete can be placed without difficulty so as to surround all prestressing tendons and reinforcements thoroughly and fill the corners of the form. *For most work, 20 mm aggregate is suitable.*
- The nominal maximum size of the aggregate shall be 5 mm less than the spacing between the tendons, sheathings, ducts or un-tensioned steel, where provided.
- Coarse and fine aggregate shall be batched separately. All-in-aggregate may be used only where specifically permitted by the engineer-in-charge.

Note: Aggregates to be used in manufacture of PSC Sleepers in Indian Railways shall be as per guidelines given in Serial No. T-39 (Fifth Revision –February 2016, RDSO, Lucknow).

Coarse Aggregate: Aggregate most of which is retained on 4.75 mm IS sieve is called Coarse aggregate. IS 383-1970 (Re-affirmed 2002) allows certain percentage of finer particles and the gradation prescribed in the code is reproduced in table below:

Table – 3 Coarse Aggregates

IS Sieve Designation	Percentage Passing for Single-Sized Aggregate of Nominal Size						Percentage Passing for Graded Aggregate of Nominal Size			
	63 mm	40 mm	20 mm	16 mm	12·5 mm	10 mm	40 mm	20 mm	16 mm	12·5 mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
80 mm	100	—	—	—	—	—	100	—	—	—
63 mm	85 to 100	100	—	—	—	—	—	—	—	—
40 mm	0 to 30	85 to 100	100	—	—	—	95 to 100	100	—	—
20 mm	0 to 5	0 to 20	85 to 100	100	—	—	30 to 70	95 to 100	100	100
16 mm	—	—	—	85 to 100	100	—	—	—	90 to 100	—
12·5 mm	—	—	—	—	85 to 100	100	—	—	—	90 to 100
10 mm	0 to 5	0 to 5	0 to 20	0 to 30	0 to 45	85 to 100	10 to 35	25 to 55	30 to 70	40 to 85
4·75 mm	—	—	0 to 5	0 to 5	0 to 10	0 to 20	0 to 5	0 to 10	0 to 10	0 to 10
2·36 mm	—	—	—	—	—	0 to 5	—	—	—	—

Fine Aggregates: Aggregate most of which passes through 4.75 mm IS sieve is called Fine Aggregate. An oversize of 5 to 10% is permitted by IS 383-1970(Re-affirmed 2002). Aggregate is classified in four zones as indicated in table below:

Table – 4 Fine Aggregates

IS Sieve Designation	Percentage Passing for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4·75 mm	90-100	90-100	90-100	95-100
2·36 mm	60-95	75-100	85-100	95-100
1·18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

Sieve analysis: As per IS specifications following standard sieves are used to carry out sieve analysis:

Coarse Agg.	80MM	40MM	20MM	10MM	4.75MM
Fine Agg.	2.36MM	1.18MM	600µ	300µ	150µ 75µ

% retained on each sieve should be recorded.

Minimum weight of sample for sieve analysis: The minimum weights of samples required are specified in IS 2386 (Pt-I):1963 are reproduced in Table - 5 below:

Table – 5 Minimum Weights for Sampling
(Clause 2.4.4, 2.5 and 2.5.2) IS2386 (Pt-I):1963

Maximum Size Present in Substantial Proportions	Minimum Weight of Sample to be Taken for Sieving
mm	kg
63	50
50	35
40 or 31·5	15
25	5
20 or 16	2
12·5	1
10	0·5
6·3	0·2
4·75	0·2
2·36	0·1

- As per IS-2386(Pt. I):1963, the material finer than 75µ should not be more than 3%.

Fineness Modulus: The concept of fineness modulus was evolved by Abrahms. It is an empirical factor obtained by adding cumulative %aggregate on each sieve and dividing the sum by 100. Larger the value, coarser is the material. Based on fineness modulus, sand is divided in three categories.

Category of Sand	Fineness Modulus
Fine sand	2.2 to 2.6
Medium sand	2.6 to 2.9
Coarse sand	2.9 to 3.2

Sand having FM of more than 3.2 is considered unsuitable for concrete making.

An example of working out FM is given below

IS Sieve (mm)	Wt retained (gms)	CummulativeWt (gms)	Cummulative % Wt (gms)
4.75mm	10	10	2
2.36mm	50	60	12
1.18mm	50	110	22
600 µ	95	205	41
300 µ	175	380	76
150 µ	85	465	93
Dust	35	500	-
	500 gms		246

FM = 246/100 = 2.46 (Fine sand)

3.5.3 जल / Water

The requirements of water used for mixing and curing shall conform to the requirements given in 5.4 of IS 456:2000. However, use of sea water is prohibited.

- Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances.
- Potable water is generally considered satisfactory for mixing concrete. As a guide the following concentrations represent the maximum permissible values:

a) To neutralize 100 ml sample of water, using phenolphthalein as an indicator, it should not require more than 5 ml of 0.02 normal NaOH.
b) To neutralize 100 ml sample of water, using mixed indicator, it should not require more than 25 ml of 0.02 normal H_2SO_4.
c) Permissible limits for solids shall be as given in Table – 6.

Table – 6 Permissible Limits of Solids (Clause 5.4 of IS 456:2000)

Solids	**Permissible limits, max**
organic	200mg/l
Inorganic	
Sulphates (as SO_3)	3000mg/l
Chlorides (as Cl)	400 mg/l
Suspended matter	2000 mg/l for concrete not containing embedded steel 500 mg/l for reinforced concrete work

Note:

a) The pH value of water shall be not less than 6.
b) Mixing or curing of concrete with sea water is not recommended because of presence of harmful salts in sea water.
c) Water found satisfactory for mixing is also suitable for curing concrete.
d) The presence of tannic acid or iron compounds is objectionable.

3.5.4 मिश्रण / Admixture

The Chief Engineer may permit the use of admixtures for imparting special characteristics to the concrete or mortar on satisfactory evidence that the use of such admixtures does not adversely affect the properties of concrete or mortar particularly with respect to strength, volume change, durability and has no deleterious effect on reinforcement.

- The admixtures, when permitted, shall conform to IS:9103.
- Calcium chloride or admixtures containing calcium chloride shall not be used in structural concrete containing reinforcement, prestressing tendons or other embedded metal.
- The admixture containing Cl & SO_3 ions shall not be used.
- Admixtures containing nitrates shall not be used.
- Admixtures based on thiocyanate may promote corrosion and therefore shall be prohibited.
- Generally one admixture at a time should be used.

- The admixture should be stored as per specified conditions by its manufacturer and its shelf life should be monitored continuously.
- All containers should be correctly leveled. Reliable liquid dispenser for liquid admixtures should be used and calibrated.

Note: The use of Admixture (Plasticizer) in manufacture of PSC Sleepers may be necessitated as instructed by Railway Board.

GOVERNMENT OF INDIA/ भारत सरकार
MINISTRY OF RAILWAYS/ रेल मंत्रालय
(RAILWAY BOARD/ रेलवे बोर्ड)

Sub: Corrigendum No. 1 to E-Tender No. CS169of2016 for manufacture and supply of Pre-stressed Mono-Block Concrete Sleepers (opening on 27.06.2016)

Clause - 4.5 of "Special Conditions of Contract" (Annexure - I of Tender Document) is modified as under:

"The cement content in the concrete mix shall not be more than 450 Kg/cum. This may necessitate use of plasticizer, which shall be procured by contractor as per requirements laid in clause 3.2.4 of IRS-T-39. Quoted rate shall be inclusive of cost of plasticizer/admixture."

All other terms and conditions shall remain unchanged.

14/6/16
(Vinod K. Tripathi)
Director Track (M)
Railway Board
Tel/Fax – 2338 9161

<u>Water reducing Admixtures</u>: There are two categories of water reducing admixtures.

(i) Plasticizers (ii) Super-plasticizers

Super-plasticizers are improvised version of conventional plasticizers. They reduce water requirement significantly. These are, therefore, also called 'High range water reducers'. Plasticizers reduce water requirement up to 15% whereas super plasticizers can reduce this requirement even up to 30%.

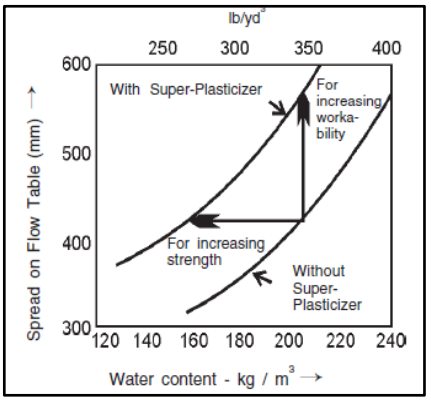
The effect of super-plasticizer can be understood in a better way by analysing the following results and curves.

Mix	Cement kg/m^3	W/C	Slump (mm)	Strength (N/mm^2)	
				7 Days	28 Days
Mix with cement only	440	0.37	25	39	54
Cement + .4% Admixture	440	0.37	100	41.1	54.1

Effect on Workability (keeping w/c same)

Mix	Cement kg/m^3	W/C	Slump (mm)	Strength (N/mm^2)	
				7 Days	28 Days
Mix with cement only	440	0.37	25	39	54
Cement + .4% Admixture	440	0.37	100	41.1	54.1

Effect on Strength (keeping workability same)



Note: The percentage of admixture is by weight of cement.

[Reference: Concrete Technology, October 2007 (Corrected & Reprinted: January 2014), IRICEN, Pune**]**

3.6 कंक्रीट के गुण / Properties of Concrete

3.6.1 कार्यशीलता / Workability

The concrete mix proportions chosen should be such that the concrete is of adequate workability for the placing conditions of the concrete and can properly be compacted with the means available. Suggested ranges of values of workability of concrete are given in IS 456:2000.

There are four types of workability:

i) Very low: Concreting of lightly reinforced section with vibration (0-25 mm slump)
ii) Low: Concreting of lightly reinforced section with vibration (20-40 mm slump)
iii) Medium: Concreting of lightly reinforced section without (Manual compaction) or heavily reinforced section with vibration (25-75 mm slump)
iv) High: Concreting of heavily reinforced section with vibration (75-125 mm slump)

Slump Test: Height of slump cone is 30 cm. The dia. at the bottom is 20 cm. The dia. at the top is 10 cm. The slump cone is to be filled in separate 3 layers and each layer must be compacted by a compacting rod of 16 mm dia., 60mm long, 25 times distributing over full area. Procedure of filling slump must be completed within 3 minutes, than slump cone lifted immediately vertically and allow the concrete to settle, measure the slump by keeping slump inverted and keeping steel rod across the mould with scale in mm.

3.6.2 सामर्थ्य / Strength

Concrete is subjected to considerable variation in strength due to wide variation in the characteristics of concrete constituents (sand, coarse aggregates etc.), Also, due to non-homogeneous nature of concrete, specimens taken from the same mix may give different compressive strengths in tests. This variation can be controlled by strict quality control and quality assurance.

Coefficient of variation: Statistically, the *variation in concrete strength* is studied in terms of standard deviation and / or coefficient of variation.

Coefficient of variation = Standard deviation/Mean strength

The coefficient of variation varies generally in the range of 0.01 to 0.02. With higher degree of quality control, this variation can be reduced.

Standard Deviation: The standard deviation for each grade of concrete shallbe calculated separately.

- *Standard deviation based on test strength of sample*

  - Attempts should be made to obtain the 30 samples, as early as possible, when a mix is used for the first time.
  - When significant changes are made in the production of concrete batches (for example, changes in the materials used, mix design, equipment or technical control), the standard deviation value shall be separately calculated for such batches of concrete.
  - The calculation of the standard deviation shall be brought up to date after every change of mix design.

- *Assumed standard deviation:* Where sufficient test results for a particular grade of concrete are not available, the value of standard deviation shall be assumed to be 5.0 N/mm^2 for design of mix in the first instance. As soon as the results of samples are available, actual calculated standard deviation shall be used and the mix designed properly.

Characteristic Strength

Characteristic strength of concrete is defined as the strength of the material below which not more than 5% of the tests results are expected to fall.

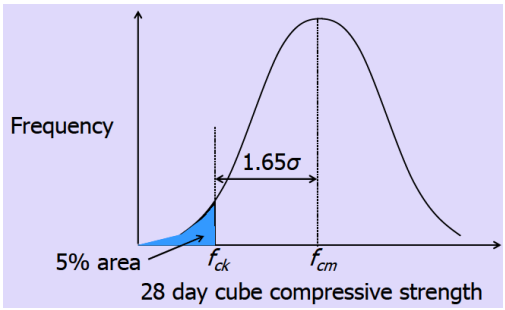
1. Strength of concrete in uniaxial compression is determined by testing a standard cube of 150 mm and is loaded till its failure.
2. The cube specimen is tested after 28 days of casting and curing.
3. The strength of cube is always expressed nearest to 0.5 N/mm^2.
   - At higher rate of loading, the compressive strength increases. The increment is from 30% to almost 50% of the original strength.
4. As per IS 456:2000, there should be three specimens in a sample.
5. Strength of sample is expressed as an average of three specimens of the sample.
6. Individual variation in the strength of cubes should not vary by more than ± 15% of average strength and if the variation is more than the test results are discarded.

Target Mean (average) Strength of Concrete: Thus, mean strength of concrete must be significantly greater than the characteristic strength of concrete.

$$f_{cm} = f_{ck} + 1.65\ \sigma$$

Where,

f_{ck} = characteristic compressive strength at 28 days,
f_{cm} = target average compressive strength
σ = standard deviation.



The figure shows the probability density function associated with the standard normal variable. The definition of characteristic strength of concrete is based on this function. As per the definition, 95% of the specimens (cubes having strength equal or more than the required strength) should possess a strength greater than the characteristic compressive strength (f_{ck}) of concrete. From the probability density function, this corresponds to a value of 1.65 for the standard normal variable. The value of 1.65 is based upon the provision that 5% of the test results can be accepted having lower than the required strength.

Difference between Compressive Strength and Characteristic Strength

- Compressive strength – the applied pressure at which a given concrete sample fails.
- Characteristic strength – Suppose, there is a certain number of samples from a particular batch of concrete. Characteristic strength would be that compressive strength below which not more 5% of the samples are expected to fail. Thus, at last 95% of the samples have higher compressive strength than the characteristic strength.

Cube Casting and Testing: As per IS 456:2000, minimum frequency of sampling of concrete of each grade shall be in accordance with the Table – 7.

- Cubes are cast with same concrete which is being used in structure.
- Cubes must be placed in a separate water tank of shallow depth or as guided by engineer in-charge of work. At least one sample is to be taken from each shift.
- A sample means 3 cubes. In one sample, the strength of individual cube should not vary by more than ± 15% of average strength, otherwise the sample is considered to be invalid. At the time of testing, the rate of loading should not be more than 14 N/mm^2 per minute, otherwise the results will not be accurate.

Table – 7 Frequency of Sampling for Each Grade of Concrete (Clause 15.2.2 of IS 456:2000)

Quantity of Concrete in the Work, m^3	*Number of Samples*
1 - 5	1
6 - 15	2
16 - 30	3
31 - 50	4
51 and above	4 plus one additional sample for each additional 50 m^3 or part thereof

3.6.3 दृढ़ता / Durability

Cube testing alone is not the criteria for the durability of concrete structure. A durable concrete is one that perform satisfactorily in the working environment during its anticipated exposure conditions during service. The durability of concrete is intrinsically related to its water tightness

or permeability. The concrete should have low permeability and there should be adequate cover to reinforcing bars. The selection of proper materials and good quality control are essential for durability of concrete.

- The materials and mix proportions specified and used should be such as to maintain its integrity and if applicable, to protect embedded metal from corrosion.
- Every concrete structure should continue to perform its intended functions, i.e. to maintain its required strength and serviceability, during the specified or traditionally expected service life.
- Concrete is said to be durable, if it is able to withstand the processes of deterioration to which it can be expected to be exposed.
- Both strength and durability have to be considered explicitly at the design stage.

The common durability problems in concrete are as follows.

1) Sulphate and other chemical attacks of concrete.
2) Alkali-aggregate reaction.
3) Freezing and thawing damage in cold regions.
4) Corrosion of steel bars or tendons.

The factors, which influence the durability of concrete include, a) Environment, b) Cover to embedded steel, c) Type and quality of constituent materials, d) Cement content and water-cement ratio of the concrete, e) Workmanship to obtain full compaction and efficient curing, and f) Shape and size of the member

The degree of exposure anticipated for the concrete during its service life together with other relevant factors relating to mix composition, workmanship, design and detailing should be considered.

Note:

(i) Permeability test shall be mandatory for all RCC/ PSC bridges under severe and extreme environment;
(ii) Under moderate environment, permeability test shall be mandatory for all major bridges and for other bridges permeability test is desirable to the extent possible;
(iii) Permeability test is required for RCC/ PSC structural element only.

3.7 कंक्रीट के ग्रेड / Grade of Concrete

The grade of concrete is expressed in terms of its characteristic compressive strength (of 150 mm cube at 28 days) in N/mm^2 or MPa, e.g. M20, M25, M30, M40 and so on. In the recent revised version of IS 456:2000, minimum grade of concrete is based on considerations of durability and the type of environment that the structure is exposed to. Minimum concrete grade in RCC has been upgraded from M15 to M20 in IS 456:2000.

Minimum grade of concrete as per exposure conditions is shown as in Table - 8. The minimum grades of concrete for prestressed applications are as follows.

- 30 MPa for post-tensioned members
- 40 MPa for pre-tensioned members.

The maximum grade of concrete is 60 MPa. For concrete greater than M 60, design parameters given in the IS 1343:2012 may not be applicable and the values may be obtained from specialized literatures and experimental results.

Table - 8 Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size (*Clauses* 8.2.4.1 *and* 9.1.2 of IS 1343:2012)

Sl No.	Exposure	Prestressed Concrete		
		Minimum Cement Content kg/m^3	Maximum Free Water Cement Ratio	Minimum Grade of Concrete
(1)	(2)	(3)	(4)	(5)
i)	Mild	300	0.55	M 30
ii)	Moderate	300	0.50	M 30
iii)	Severe	320	0.45	M 30
iv)	Very severe	340	0.45	M 35
v)	Extreme	360	0.40	M 40

3.8 कंक्रीट मिक्स डिज़ाइन / Concrete Mix Design

It is a process of selecting suitable ingredients and determining their relative proportions with the objective of producing concrete of having certain minimum workability, strength and durability as economically as possible.

Design of a mix not only needs the knowledge of properties of all ingredients and the properties of concrete in plastic condition, but it also requires wider knowledge and experience of concreting. A mix can be designed in two ways as: 1. Nominal Mix 2. Design Mix

3.8.1 सामान्य मिक्स / Nominal Mix

It is used for relatively unimportant and simpler concrete works. In this type of mix, all the ingredients are prescribed and their proportions are specified.

- Nominal mix concrete may be used for concrete of M 20 or lower. The proportions of materials for nominal mix concrete shall be in accordance with Table - 9 of IS 456:2000.
- The cement content of the mix as specified IS 456:2000 for any nominal mix shall be proportionately increased if the quantity of water in a mix has to be increased to overcome the difficulties of placement and compaction, so that the water-cement ratio as specified is not exceeded.

Proportions of materials for nominal mix concrete

Grade	Max. Qty of Dry Aggregates per 50 kg of cement	FA : CA by mass	Max. quantity of water in litres
M-5	800	Generally 1:2 but may varies from 1:15 to 1:2.5	60
M-7.5	625		45
M-10	480		34
M-15	330		32
M-20	250		30

3.8.2 डिजाइन मिक्स कंक्रीट / Design Mix Concrete

It is a performance based mix where choice of ingredients and proportioning are left to the designer to be decided. The user has to specify only the requirements of concrete in fresh as well as hardened state. The requirements in fresh concrete are workability and finishing characteristics, whereas in hardened concrete these are mainly the compressive strength and durability.

Based on IS method (IS 10262:2009),

- The mix shall be designed to produce the grade of concrete having the required workability and a characteristic strength not less than the appropriate values given in Table – 8 for prestressed concrete.
- The target mean strength of concrete mix should be equal to the characteristic strength plus 1.65 times the standard deviation.
- Mix design done earlier not prior to one year may be considered adequate for later work provided there is no change in source and the quality of the materials.

The procedure for designing a concrete mix (both for medium strength and high strength concrete) is as follows:

Step – 01: Data to be required

Grade designation of specified characteristic compressive strength of 150 mm cube at 28 days in N/mm^2	M40
Type of cement	OPC – 43
Fine aggregate	Zone – 1
Workability	100 mm (Slump)
Sp. Gravity of Cement	3.15
Sp. Gravity of coarse aggregate	2.74
Sp. Gravity of fine aggregate	2.74
Cement content – maximum	450 Kg/m^3
Cement content – minimum	320 Kg/m^3
Water absorption – coarse aggregate	0.5%
Water absorption – fine aggregate	1.0%
Max. Nominal size of coarse aggregate	20 mm
Max. water cement ratio	0.45
Chemical admixture	Superplasticiser
Sp. Gravity of admixture	1.145
Free (surface) moisture – coarse aggregate	1% (absorbed moisture)
Free (surface) moisture – fine aggregate	2%
Exposure conditions	Severe

Step – 02 Target Mean strength

Target mean strength for mix design is the characteristic strength of concrete, which is defined as 'that value below which not more than 5% test results are expected to fall'.

$f_{cm} = f_{ck} + 1.65\sigma$
$= 40 + 1.65*5.0$
$= 48.25$ MPa (N/mm^2)

Where,

f_{cm} = target mean compressive strength at 28 days,
f_{ck} = characteristic compressive strength at 28 days, and
σ = standard deviation.

From Table – 10, standard deviation, σ=5 N/mm^2

Table 10 Assumed Standard Deviation
***(Clauses* 3.2.1.2, A-3 *and* B-3 of IS 10262:2009)**

Sl No. (1)	Grade of Concrete (2)	Assumed Standard Deviation N/mm^2 (3)
i)	M 10	3.5
ii)	M 15	
iii)	M 20	4.0
iv)	M 25	
v)	M 30	5.0
vi)	M 35	
vii)	M 40	
viii)	M 45	
ix)	M 50	
x)	M 55	

Step – 03 Water/Cement Ratio

For desired exposure conditions, the W/C ratio shall be taken in accordance to Table –8 to ensure durability requirements of concrete. Maximum water-cement ratio is 0.45.

Based on experience, adopt water-cement ratio as 0.40. 0.40 < 0.45, hence O.K.

Step – 04 Calculation of Water Content

- Table – 11 is to be referred for max. water content per cum of concrete for nominal max. size of aggregate.
- Water content in Table – 11 is for angular coarse aggregate and for 25 to 50 mm slump range.
- For the desired workability (other than 25 to 50 mm slump range), the required water content may be established by trial or an increase by about 3% for every additional 25 mm slump or alternatively by use of chemical admixture conforming to IS 9103.
- Water reducing admixture or superplasticisers admixture usually decrease water content by 5 to 10% and 20% and above respectively at appropriate dosages.

Table – 11 Maximum Water Content per Cubic Metre of Concrete for Nominal Maximum Size of Aggregate
***(Clauses* 4.2, A-5 *and* B-5 of IS 10262:2009)**

Sl No. (1)	Nominal Maximum Size of Aggregate mm (2)	Maximum Water Content [1] kg (3)
i)	10	208
ii)	20	186
iii)	40	165

NOTE — These quantities of mixing water are for use in computing cementitious material contents for trial batches.

[1] Water content corresponding to saturated surface dry aggregate.

Max. water content for nominal max. size of aggregate (20mm) = 186 litre
Estimated water content for 100 mm slump = 186 + (6/100)*186 = 197 litre

As superplasticiser is used, the water content can be reduced by 20% and above. Based on trials, the water content can be reduced by 29%.

Hence, the arrived water content = 197*0.71 = 140 litre

Step – 05 Cement Content

Table – 8 is referred for desired exposure conditions as preliminary w/c ratio 0.40, the mixing water content is 140 litre of concrete.

Cement content = 140/0.4 = 350 kg/m^3

From Table - 8, min. cement content for 'severe' exposure condition = 320 kg/m^3

350 kg/m^3 > 320 kg/m^3. Hence, O.K.

Step – 06 Proportion of Volume of Coarse Aggregate and Fine Aggregate Content

From Table – 12, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60.

In the present case, water-cement ratio is 0.40. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.10. The proportion of volume of coarse aggregate is increased by 0.02 (at the rate of -/+ 0.01 for every ± 0.05 change in water-cement ratio).

Table 12 Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate
***(Clauses* 4.4, A-7 *and* B-7 of IS 10262:2009)**

Sl No.	Nominal Maximum Size of Aggregate	Volume of Coarse Aggregate[1)] per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate			
	mm	Zone IV	Zone III	Zone II	Zone I
(1)	(2)	(3)	(4)	(5)	(6)
i)	10	0.50	0.48	0.46	0.44
ii)	20	0.66	0.64	0.62	0.60
iii)	40	0.75	0.73	0.71	0.69

[1)] Volumes are based on aggregates in saturated surface dry condition.

Therefore, corrected proportion of volume of coarse aggregate for the w/c ratio of 0.40 = 0.62.

NOTE - In case the coarse aggregate is not angular one, then also volume of coarse aggregate may be required to be increased suitably, based on experience.

For pumpable concrete, these values should be reduced by 10 percent.

Therefore, volume of coarse aggregate = 0.62 x 0.9 = 0.56.
Volume of fine aggregate content =1 – 0.56 =0.44.

Step – 07 Mix Calculations

The mix calculations per unit volume of concrete shall be as follows:

a) Volume of concrete = 1 m^3

b) Volume of cement = (Mass of cement/ Sp. Gravity of cement)/1000
= (350/3.15)/1000 = 0.111 m^3

c) Volume of water = (Mass of water/ Sp. Gravity of water)/1000
= (140/1)/1000 = 0.140 m^3

d) Volume of chemical admixture (@ 2.0 percentby mass of cementitious material) = (Mass of Chemical admixture/Sp. Gravity of admixture)/1000 (superplasticizer)
= (7/1.145)/1000 = 0.006 m^3

e) Volume of all in aggregate = [a- (b +c +d)]
= [1-(0.111+0.140+0.006)] = 0.743 m^3

f) Mass of coarse aggregate = e) X volume of coarse aggregate X sp. gravity of coarse aggregate X 1000
= 0.743 X 0.56 X 2.74 X 1000= 1140 kg

g) Mass of fine aggregate = e) X volume of fine aggregate X sp. gravity of fine aggregate X 1000
= 0.743 X 0.44 X 2.74 X 1000= 896 kg

Step – 08 Proportions

Ingredients	**Cement**	**Fine aggregate**	**Coarse aggregate**	**Water**	**Chemical admixture (superplasticiser)**
Quantity (kg/m3)	350	896	1140	140	7
Ratio	1.0	2.56	3.25	0.4	
1 bag cement (kg)	50.0	128	162.5	20.0	

Step – 09 Adjustments for field condition

- Fine Agg. has surface moisture of 2%; Weight of fine aggregate = 896 (1+0.02) = 913.92 kg

- Coarse Agg. absorbed 1% water; Weight of coarse aggregate = 1140 (1-0.01) = 1128.60 kg

Ingredients	**Cement**	**Fine aggregate**	**Coarse aggregate**	**Water**	**Chemical admixture (superplasticiser)**
Quantity (kg/m^3)	350	913.92	1128.60	140	7
Ratio	1.0	2.61	3.22	0.4	
1 bag cement (kg)	50.0	130.5	161.0	20.0	

3.9 कंक्रीट उत्पादन में सम्मिलित प्रक्रियाएं / Processes involved in Concrete Production

Production of concrete involves two distinct activities. One is related to 'material' and the other to 'processes'. The material part is generally taken care by everybody, but the involved processes in the production of concrete are often neglected. Therefore, no wonder that it is the 'process' which is responsible for good or bad quality of concrete. If we take care of processes, the quality of concrete will be improved automatically without incurring any extra expenditure as the major expenditure has already been made in procurement of material. In order to ensure the quality, it is very important to have knowledge of each and every process.

The various processes involved in concrete production are as given below:

1) Batching 2) Mixing 3) Transportation
4) Placement and Compaction 5) Curing

3.9.1 बैचिंग / Batching

- In batching concrete, the quantity of both cement and aggregate shall be determined by mass; admixture, if solid, by mass; liquid admixture may however be measured in volume or mass; water shall be weighed or measured by volume in a calibrated tank.
- For large and medium project sites the concrete shall be sourced from ready-mixed concrete plants or from on site or off site batching and mixing plants.
- The grading of aggregate should be controlled by obtaining the coarse aggregate in different sizes and blending them in the right proportions, the different sizes being stocked in separate stock-piles.
- The material should be stock-piled for several hours preferably a day before use. The grading of coarse and fine aggregate should be checked as frequently as possible, the frequency for a given job being determined by the engineer-in-charge to ensure that the specified grading is maintained.
- The accuracy of the measuring equipment shall be within ±2 percent of the quantity of cement being measured and within ±3 percent of the quantity of aggregate, admixtures and water being measured.
- Proportion/type and grading of aggregates shall be made by trial in such a way so as to obtain densest possible concrete.
- It is important to maintain the water-cement ratio constant at its correct value.
- For the determination of moisture content in the aggregates, IS 2386 (Part 3) may be referred to. To allow for the variation in mass of aggregate due to variation in their moisture content, suitable adjustments in the masses of aggregates shall also be made.

3.9.2 मिक्सिंग / Mixing

- Concrete shall be mixed in a mechanical mixer. The mixers shall be fitted with water measuring (metering) devices.
- The weighed quantity of all the dried ingredients is placed into hopper.

- After this about half of the required amount of water to be added into drum and hopper is stirred mechanically and material falls into drum which is rotated. The remaining quantity of water is to be poured into mixer after 1/4th of the mixing time is over.
- The time of mixing should be about 1 ½ minutes to 2 minutes (approximately 45 to 50 revolution of the drum is required to make concrete uniform colour and homogeneous).
- Workability should be checked at frequent intervals.
- Dosages of retarders, plasticizers and superplasticizers shall be restricted to 0.5, 1.0 and 2.0 percent respectively by mass of cementitious materials unless a higher value is agreed upon between the manufacturer and the constructor based on performance test.
- If there is segregation after unloading from the mixer, the concrete should be remixed.

3.9.3 परिवहन / Transportation

- After mixing, concrete shall be transported to the formwork as rapidly as possible by maintaining the required workability. During hot or cold weather, concrete shall be transported in deep containers.

3.9.4 प्लेसमेंट और संघनन / Placement and Compaction

- *Placement:* The concrete shall be deposited as nearly as practicable in its final position to avoid re-handling. The concrete shall be placed and compacted before initial setting of concrete commences and should not be subsequently disturbed. Care should be taken to avoid displacement of reinforcement or movement of formwork. As a general guidance, the maximum permissible free fall of concrete may be taken as 1.5 m.
- *Compaction:* Concrete should be thoroughly compacted and fully worked around the reinforcement, around embedded fixtures and into comers of the formwork.
    - Concrete shall be compacted using mechanical vibrators complying with IS 2505, IS 2506, IS 2514 and IS 4656. Over vibration and under vibration of concrete are harmful and should be avoided. Vibration of very wet mixes should also be avoided.

3.9.5 क्यूरिंग / Curing

Curing is the process of preventing the loss of moisture from the concrete whilst maintaining a satisfactory temperature regime. The prevention of moisture loss from the concrete is particularly important,

- *if the water-cement ratio is low,*
- *if the cement has a high rate of strength development,*
- *if the concrete contains granulated blast furnace slag or pulverised fuel ash*
- *if high temperature gradients within the concrete develops*

- **Moist Curing**: Exposed surfaces of concrete shall be kept continuously in a damp or wet condition by ponding or by covering with a layer of sacking, canvas, hessian or similar materials and kept constantly wet for at least seven days from the date of placing concrete in case of ordinary Portland Cement and at least 10 days where mineral admixtures or blended cements are used. The period of curing shall not be less than 10 days for concrete exposed to

dry and hot weather conditions. In the case of concrete where mineral admixtures or blended cements are used, it is recommended that above minimum periods may be extended to 14 days.

- **Membrane Curing**: Approved curing compounds may be used in lieu of moist curing with the permission of the engineer-in charge. Such compounds shall be applied to all exposed surfaces of the concrete as soon as possible after the concrete has set. Impermeable membranes such as polyethylene sheeting covering closely the concrete surface may also be used to provide effective barrier against evaporation.

- **Steam-Curing**: Steam curing can be advantageously used to save time of curing of concrete for transfer of prestress. However, it has been found satisfactory to use a pre-steaming period of 4 to 5 hour or rate of temperature rise between 22-33 ^{0}C per hour and a maximum curing temperature of 66-82^0 C for a period such that entire curing cycle does not exceed 18 hour.
  - Rapid temperature changes during the cooling period should be avoided and drop in ambient temperature in the enclosure is not sharper than 20^0 C per hour. The reuse of casting beds and forms along with 18 hour steam curing makes it a total 24 hour cycle.
  - Prestress to members in pretension beds should be transferred immediately after the termination of steam curing while the concrete and forms are still warm, otherwise the temperature within the enclosure shall be maintained at over 15^0 C until the prestress is transferred to the concrete.

  The steam curing will be considered complete when the concrete has reached the minimum strength at 'Strength at Stress transfer' or handling strength.

3.10 बट्टेड असेम्बली को जोड़ना / Jointing of Butted Assemblies

- The joints of butted assemblies shall be made of either cement grout or cement mortar or concrete.
  - Cement grouting shall be used for joints up to 12 mm thick.
  - Cement mortar shall be used for joints thicker than 12 mm and up to 75 mm,.
  - Where joints exceeding 75 mm are encountered, the joint shall be made up of concrete.
  - Use of epoxy may be permitted with the approval of engineer-in-charge.

- The stressing operations may be carried out in case of mortar joints immediately after placing the mortar but the stress in the mortar shall not exceed 7.0 N/mm^2.
- In the case of grouted joints and concrete joints, the allowable stress in the first 24 h after placing of the grout or concrete in the joint shall approximate as closely as possible to the strength of the grout or concrete used.
- The holes for the prestressing tendons shall be accurately located and shall be in true alignment when the units are put together.
- Full tensioning shall not be carried out until the strength of the concrete or mortar in the joint has reached twice the stress at transfer.

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अध्याय / Chapter – 4

पूर्वप्रबलन स्टील / Prestressing Steel

4.1 अतनाव स्टील / Un-tensioned Steel

The role of reinforcing steel is secondary to the structural behavior and is concerned with stress distribution and crack prevention. The reinforcement used as un-tensioned steel shall be any of the following:

a) Mild steel and medium tensile steel bars conforming to IS 432 (Part 1).
b) High strength deformed steel bars conforming to IS 1786.
c) Hard-drawn steel wire fabric conforming to IS 1566.

Note: For Seismic Zones III, IV & V; HSYD steel bars having minimum elongation of 14.5 percent and conforming to other requirements of IS: 1786 shall be used. (CS – 3, dtd 20.01.2015 of IRS Concrete Bridge Code: 1997)

4.2 पूर्वप्रबलन स्टील / Prestressing Steel

For prestressed concrete members, the high tensile steel used generally consists of wires, bars, or strands. Such element when used to impart prestress to concrete on tensioning is called tendon.

The prestressing steel shall be any one of the following:

(a) Plain hard-drawn steel wire conforming to IS: 1785 (part-I).
(b) Uncoated stress-relieved strand conforming to IS: 6006.
(c) High tensile steel bars conforming to IS: 2090.
(d) Uncoated stress relieved low relaxation strands conforming to IS: 14268.

Wires conforming to IS: 1785-1983 (Part-I) (Re-affirmed 2008): The wire made of base metal i.e. carbon steel when drawn to suitable round wire sizes is used to fabricate into proper strand sizes.

The following values specified to nominal diameters of the finished wires shall be as per the table below:

Nominal Diameter of Bars		Nominal Mass of Bars		Tensile strength*, *Min* N/mm^2	Elongation after fracture over a gauge length of 200mm, *Min* percent
Diameter mm	Tolerances mm	Mass g/m	Tolerances g/m		
8.00	± 0·05	395	± 5.9	1375	4.0
7.00	± 0·05	302	± 4.3	1470	4.0

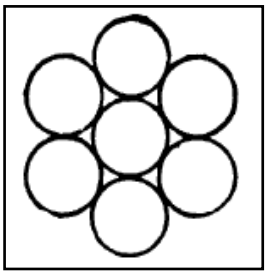
5.00	± 0·05	154	± 3.1	1570	4.0
4.00	± 0·05	98.9	± 2.0	1775	3.0
3.00	± 0·04	55.5	± 1.5	1865	2.5
2.50	± 0·025	38.5	± 1.25	2010	2.5

* Wires of diameter 5, 7 and 8 mm may be manufactured to give higher minimum tensile strength. In such cases, minimum tensile strength of 1715, 1570 and 1470 N/mrn^2 are recommended for wires of nominal diameter 5, 7 and 8 mm respectively; but other requirements shall remain the same.

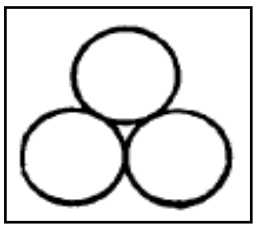
The relaxation stress in the wire, when tested in accordance with 7.7 of IS: 1785-1983 (Part-I) (Re-affirmed 2008) shall not exceed 5 percent of the initial stress at the end of 1,000 hrs.

Strand conforming to IS: 6006:1983 (Re-affirmed 2008): A group of wires laid helically over a central-core wire is termed as strand.

- **Seven Wire Strand** – Any length of finished material which comprises six wires spun together in helical form around a central wire. The seven wire strand shall be designated by the approximate overall diameter of the strand and number of element wires (plies) making the strand. For example, 6.3 mm 7-ply strand will mean a strand of approximate diameter 6.3 mm and made out of seven (six outer and one central) wires.



- **Three wire Strand** – Any length of finished material which comprises three wires spun together in helical form. The three wire strand shall be designated by the number of element wires (plies) and the diameter of the element wire making the strand. For example, 3-ply 3 mm strand will mean a strand consisting of three element wires of diameter 3.0 mm each.



- **Two Wire Strand** – Any length of finished material which comprises two wires spun together in helical form. The two wire strand shall be designated by the number of element wires (plies) and the diameter of the element wire making the strand. For example, 2-ply 2 mm strand will mean a strand consisting of two element wires of diameter 2.0 mm each.



The following values specified to Dimensions, Tolerances and Mass of Two and Three Wire Strands shall be as per the table below:

Designation	**Nominal dia. of element wire mm**	**Tolerance on dia. of element wire mm**	**Nominal cross section area of strand mm^2**	**Nominal mass of strand kg/m**
2-ply 2 mm	2.0	± 0.03	6.28	0.0493
2-ply 3 mm	3.0	± 0.03	14.14	0.111
3-ply 3 mm	3.0	± 0.03	21.21	0.166

The following values specified to Dimensions, Tolerances and Mass of Seven Wire Strands shall be as per the table below:

Class	Designation	Nominal dia. of strand mm	Tolerance on nominal dia. of strand mm	Nominal cross section area of strand mm^2	Nominal mass of strand kg/m
1	6.3 mm 7-ply	6.3	± 0.4	23.2	0.182
	7.9 mm 7-ply	7.9	± 0.4	37.4	0.294
	9.5 mm 7-ply	9.5	± 0.4	51.6	0.405
	11.1 mm 7-ply	11.1	± 0.4	69.7	0.548
	12.7 mm 7-ply	12.7	± 0.4	92.9	0.730
	15.2 mm 7-ply	15.2	± 0.4	139.4	1.094
2	9.5 mm 7-ply	9.5	+0.66, –0.15	54.8	0.432
	11.1 mm 7-ply	11.1	+0.66, –0.15	74.2	0.582
	12.7 mm 7-ply	12.7	+0.66, –0.15	98.7	0.775
	15.2 mm 7-ply	15.2	+0.66, –0.15	140.0	1.102

Note: *The nominal cross-sectional area and the nominal mass of the two and three and seven wire strand as given in table above are for information only.*

The following values specified to Minimum Breaking Load of finished stress relieved strand shall be as per the table below:

Class	Designation	Breaking Load, *Min* N	0.2 Percent Proof Load N
-	2-ply 2 mm	12.750	10.840
	2-ply 3 mm	25.500	21.670
	3-ply 3 mm	38.250	32.460
1	6.3 mm 7-ply	40.000	34.000
	7.9 mm 7-ply	64.500	54.700
	9.5 mm 7-ply	89.000	75.600
	11.1 mm 7-ply	120.100	102.300
	12.7 mm 7-ply	160.100	136.200
	15.2 mm 7-ply	240.200	204.200
2	9.5 mm 7-ply	102.300	87.000
	11.1 mm 7-ply	137.900	117.200
	12.7 mm 7-ply	183.700	156.100
	15.2 mm 7-ply	260.700	221.500

The relaxation of stress in the wire, when tested in accordance to 7.4 of IS: 6006-1983 (Re-affirmed 2008), shall not exceed 5 percent of the initial stress at the end of 1000 hrs.

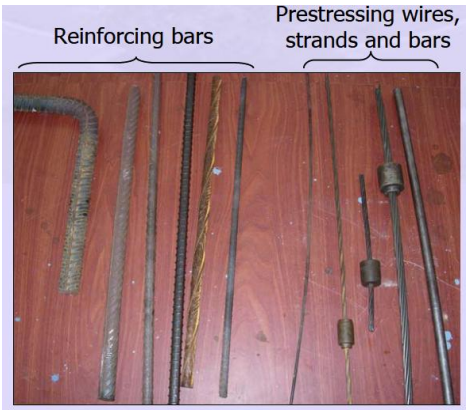
Bars conforming to IS: 2090-1983 (Re-affirmed 2009): Bar is defined as a rolled rod or bar of alloy steel of circular cross-section having a tensile strength of not less than 980 N/mm^2. The bars shall be manufactured in nominal sizes 10, 12, 16, 20, 22, 25, 28 and 32 mm dia. with tolerances ± 0·5mm for bars up to and including 25mm and ± 0·06mm for bars above 25mm.

The tolerance on mass of the finished bars shall be ± 5 percent for bars of diameter up to and including 16 mm and ± 3 percent for bars above 16 mm. When bars are ordered by mass, the mass of bars shall be calculated on the basis that high tensile steel weighs 0.785 kg/mm^2 of cross section area per metre run. When necessary, other tolerances may be agreed between the purchaser and manufacturer.

The relaxation of stress in the bar, when tested in accordance to 7.3 of IS: 2090-1983 (Re-affirmed 2009), shall not exceed 49 N/mm^2 at the end of 1000 hrs.



High Tensile Steel (IS: 6006)



- All prestressing steel shall be free from welded joints and splits, harmful scratches, surface flaws; rough, jagged and imperfect edges and other defects likely to impair its use in prestressed concrete.
- Mechanical properties data in respect of modulus of elasticity, relaxation loss at 1000 h at mean temperature of 20°C, minimum ultimate tensile strength, stress strain curve, etc shall necessarily be obtained from manufacturer.
- Prestressing steel shall be subjected to acceptance tests prior to actual use on the works.
- Coupling units and other similar fixtures used in conjunction with the wires or bars shall have an ultimate tensile strength of not less than the individual strength of the wires or bars being joined.
- The coil of HTS wires & strands shall be given anti-corrosive treatment such as water soluble oil coating before wrapping it in hession cloth or other suitable packing. During transportation, it shall be ensured that no damage is done to coils while loading and unloading. Care shall be taken to avoid mechanically damaging, work hardening or heating prestressing tendons while handling.
- Any material, which has deteriorated or has been damaged, corroded or contaminated, shall not be used for concrete work.

4.2.1 स्टील की लोचदार मापांक / Modulus of Elasticity of Steel

The value of the modulus of elasticity of steel used for the design of prestressed concrete members shall preferably be determined by tests on samples of steel to be used for the

construction. Otherwise, a value given by the manufacturer of the prestressing steel shall be considered as fulfilling the necessary requirements.

- Where it is not possible to ascertain the modulus of elasticity by test or from the manufacturer of the steel, the values as in table may be adopted.

Type of Steel	Modulus of Elasticity E_s kN/mm^2
Plain cold-drawn wires Conforming to IS:1785 (Part-I)	210
High tensile alloy steel bars Conforming to IS: 2090	200
Strands conforming to IS: 6006	195
Strands conforming to IS: 14268	195

4.2.2 पूर्वप्रबलन स्टील की सीधाई / Straightness of Prestressing Steel

- The wire or strand, as supplied, shall be self-straightening when uncoiled.
- In the case of high tensile alloy steel bars, any straightening shall be carried out by mechanical means. Bars shall not be bent when their temperature is less than 10°C.
- In no case heat shall be applied to facilitate straightening or bending of prestressing steel.
- Special precautions like coating of prestressing wires/strands/ bars/tendons shall be taken for post-tensioned prestressed concrete elements exposed to severe and extreme exposure conditions.

4.2.3 पूर्वप्रबलन स्टील की व्यवस्था एवं स्थिति / Arrangement and Positioning of Prestressing Steel

- All prestressing steel shall be carefully and accurately located in the exact positions shown in design drawings. The permissible tolerance in the location of the prestressing tendon shall be ±5mm. Curves or bends in prestressing tendon required by the designer shall be gradual and the prestressing tendon shall not be forced around sharp bends or be formed in any manner which is likely to set up undesirable secondary stresses.
- The relative position of wires in a cable, whether curved or straight, shall be accurately maintained by suitable means such as sufficiently rigid and adequately distributed spacers.
- In the case of post-tensioned work, the spacing of wires in a cable shall be adequate to ensure the free flow of grout.
- The method of supporting and fixing the tendons (or the sheaths or duct formers) in position should be such that they will not be displaced by heavy or prolonged vibration, by pressure of the wet concrete, including upwards thrust of concrete, by workmen or by construction traffic.
- The means of locating prestressing tendons should not unnecessarily increase the friction greater than that assumed in the design, when they are being tensioned.

4.2.4 पूर्वप्रबलन स्टील को जोड़ना / Jointing of Prestressing Steel

- Coupling units and other similar fixtures used in conjunction with the prestressing steel shall have an ultimate tensile strength of not less than the individual strengths of the wires or bars being joined.

- High tensile wire other than hard-drawn wire may be joined together by suitable means provided the strength of such joints is not less than the individual strengths of the wires being joined. Hard-drawn wire used in prestressed concrete work shall be continuous over the entire length of the tendon.
- High tensile steel bars may be joined together by means of couplings, provided the strength of the coupling is such that in a test of destruction, the bar shall fail before the coupling.
- Welding shall not be permitted in prestressing steel.

4.2.5 पूर्वप्रबलन स्टील को काटना / Cutting of Prestressing Steel

- All cutting to length and trimming of the ends of wires or strands shall be done by suitable mechanical cutters. Under factory conditions flame cutting may be permitted.
- Bars shall preferably be ordered to the exact length required. Any trimming required shall be done only after the bar has been tensioned and the grout has set.

4.2.6 पूर्वप्रबलन स्टील के लिए सामान्य कवर / Nominal Cover to Prestressing Steel

- *Nominal cover*: Nominal cover is the design depth of concrete cover. It is the dimension used in design and indicated in drawings.
- *Nominal cover to meet the durability requirements*
  a) Minimum values of the nominal cover which should be provided in post-tensioned work shall be the minimum clear cover from sheathing/duct at least equal to the diameter of sheathing/duct.
  b) In pre-tensioned work, the cover of concrete measured from the outside of the prestressing tendon shall be as per Table 16 of IS 456.
- *Nominal cover to meet specified period of fire resistance:* Minimum values of nominal cover of normal-weight aggregate concrete to be provided to all reinforcement including links to meet specified period of fire resistance shall be as given in Table 16A of IS 456:2000.

4.2.7 पूर्वप्रबलन स्टील के लिए स्पेसिंग / Spacing to Prestressing Steel

- In the case of single wires used in pre-tension system, the minimum clear spacing shall not be less than the greater of the following:

  a) 3 times diameter of wire, and
  b) Nominal maximum size of aggregate plus 5 mm.

- In the case of cables or large bars, the minimum clear spacing (measured between sheathings/ducts, wherever used) shall not be less than the largest of the following:

  a) 40 mm,
  b) Maximum size of cable or bar, and
  c) Nominal maximum size of aggregate plus 5 mm.

4.2.8 समूहित केबल्स / Grouped Cables

- Cables or ducts may be grouped together vertically in groups of not more than two.
- The minimum clear horizontal spacing between groups of cables or ducts of grouped cables shall be greater of the following:
  a) 40 mm, and
  b) Nominal maximum size of aggregate plus 5 mm.
- The vertical distance between groups shall not be less than 50 mm. In case there is possibility of obstruction of flow of concrete or in case of severe exposure condition, horizontal grouping should be avoided.

4.3 पूर्वप्रबलन स्टील, शीथिंग एवं एंकरेज का संरक्षण / Protection of Prestressing Steel, Sheathing and Anchorages

In all constructions of the post-tensioned type whether prestressing is subsequently bonded or not bonded with concrete, the anchorages, prestressing steel sheathing material forming ducts in concrete and anchorages shall be given adequate protection against corrosion at all stages of construction and during service life.

- *Construction with un-bonded steel embedded in concrete*

  For protection of sheathing material forming ducts, the durability requirements shall be followed. Furthermore, the internal surface of duct, prestressing steel and anchorage shall be protected by following methods in suitable combination depending upon severity of environment and extent of layers of protection considered desirable:

  a) Coating of steel and duct by reactive metals like zinc (Zn) or zinc plus aluminium (Zn +Al) preferably applied by hot dipping method.
  b) Use of non-corroding sheath material like high density polyethylene and fibre reinforced plastic.
  c) Coating of steel by non-reactive materials like epoxy (factory applied).
  d) Covering individual uncoated steel or coated steel strands/wires in sheaths formed by extrusion process in factory using non-corroding material like HDPE or similar. The space between sheathing and duct can be filled with corrosion inhibiting materials like grease and wax.
  e) In case of large size prestressing units use of protective and replaceable corrosion inhibition material for grouting the ducts such as grease, wax polyurethane foam, wherein any corrosive trace elements are controlled to remain within acceptable limits. Systems for checking the efficacy of the method during service life and provisions for replacing/making up loss of filler material shall be incorporated.
  f) External parts of anchorages and projecting cables should be covered by suitable casing and protected by suitable material and method.

For selection of appropriate method, material specifications, installation process, etc, specialist literature should be referred to.

- *Construction with un-bonded steel and anchorages not embedded in concrete (external prestressing elements)*

  The methods given above shall be applicable for this type of construction also. In addition, the material, strength and environmental resistance of the ducts forming external enclosure shall provide adequate mechanical strength and stability against environmental attack, including solar radiation. The ducts should be strong enough to resist pressure from the grouting operations.

- *Construction with post-tensioned bonded prestressing steel*

  Internal prestressing sheathing material as well as prestressing steel is protected by dense alkaline concrete cover, which shall be of quality and thickness as specified. The steel inside ducts is best protected in long terms by cement grouts. The protection by grouting can be further augmented by use of methods given below:

  a) Use of coated steel using Zn, Zn + Al or epoxy.
  b) Use of non-corroding impervious sheathing material like HDPE is beneficial. However, bond between sheathing and concrete and sheathing and grout shall be adequate as needed by design. This method is particularly suitable in presence of migrating water or variable drying/wetting condition of concrete of severe external penetration of corrosive agents.

  External parts of anchorages and projecting cables should be covered by suitable casing and protected by suitable material and method.

- *Protection during construction period*

  a) The prestressing steel, sheathing and anchorages shall be manufactured, transported and stored at site in such a way as to provide them with adequate corrosion protection. Use of proper packaging and provision of externally applied passivating agents, oil films, etc, which is carried over in factory itself is recommended.
  b) If prestressing steel/metallic sheathing material is left unprotected at site or embedded in concrete during construction period longer than two weeks, it shall be protected by flushing with oil-water mixture (for example, cutting oil) with periodic re-flushing at not more than three months interval.
  c) After stressing, the sheaths/steel shall be provided with permanent protection as soon as possible, preferably within one week. While providing protection by pressure grouting of cement, care should be taken that the neighbouring cables are not penetrated by grout. In case of doubt such cables shall be grouted in immediate sequence before the earlier grout could have set. If the earlier stressed cables are not grouted to avoid this problem, they should be protected by periodic flushing by oil-water mixture as given in (b).

4.4 पूर्वप्रबलन स्टील का भंडारण / Storage of Prestressing Steel

All prestressing steel (wire, strand and bar from which tendons are fabricated) must be protected during transportation, handling and storage. During storage at site, the following points shall be kept in mind while ensuring protection of prestressing steel from the ambient atmosphere if it is likely to be aggressive. Prestressing steel –

- Shall be stored about 300 mm above the ground in a suitably protective cover of tar paper or polythene or any other approved material.
- Protective wrapping shall be chemically neutral.
- Prestressing material shall, under no circumstances, be subjected to any welding operation or on site heat treatment or metallic coating such as galvanising.
- Wire or strand shall be stored in large diameter coils which enable the tendons to be laid out straight. As a guide, for wires above 5mm dia, coils of about 2m dia without breaks or joints shall be obtained from manufacturer and stored.
- Storage facilities and the procedures for transporting material into or out of store, shall be such that the material does not become kinked or notched.
- Shall be stored in a closed store having single door with double locking arrangements and no windows. The air inside the store shall be kept dry as far as possible by using instrument measuring the air humidity installed inside the store, with a view to eliminating the possibility of initial rusting during storage.
- Shall be coated with water solvable grease.
- Should be absolutely clean and without any sign of rust.
- Must be provided with temporary protection during storage.
- Shall be used within 3 months of its manufacture so as to avoid initial corrosion before placing in position.

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अध्याय / Chapter – 5

फॉर्म-वर्क एवं फाल्स-वर्क / Form-work and False-work

There is often confusion between the difference of Falsework and Formwork. The falsework is "a temporary structure that is used to support a permanent structure during the erection until it becomes self supporting". The formwork is "a structure which is usually temporary but can be whole or part permanent, it is used to contain poured concrete to mould it into required dimensions and support until it is able to support itself".

5.1 फाल्स-वर्क / False-work

- False-work shall be designed to meet the requirements of the permanent structure, taking into account the actual conditions of materials, environment and site conditions.
- Careful attention shall be paid to the detailing of connections and function with a view to avoiding gross errors leading to significant damage or failure.
- False-work shall be designed to cater for following loads:

  (a) Dead load of wet concrete and reinforcement;
  (b) Weight of form work;
  (c) Plant and equipment including impact;
  (d) Impact due to deposition of concrete;
  (e) Construction personnel;
  (f) Prestressing loads;
  (g) Lateral loads;
  (h) Wind loads;
  (i) Force due to water current, if any.

- All the materials shall conform to the specified quality consistent with the intended purpose and actual site condition as applicable.
- False-work plans shall include the following information:

  (a) Design Assumptions –All major design values and loading conditions shall be shown on these drawings. They include assumed values of superimposed load, rate of placement, mass of moving equipment which may be operated on formwork, foundation pressures, camber diagram and other pertinent information, if applicable.
  (b) Types of materials, sizes, lengths and connection details.
  (c) Sequence of removal of forms and shores.
  (d) Anchors, form ties, shores and braces.
  (e) Field adjustment of the form during placing of concrete.
  (f) Working scaffolds and gangways.
  (g) Weep holes, vibrator holes or access doors for inspection and placing of concrete.
  (h) Construction joints, expansion joints.

(i) Sequence of concrete placements and minimum/maximum elapsed time between adjacent placements.
(j) Chamfer strips or grade strips for exposed corners and construction joints.
(k) Foundation details for false-work.
(l) Special provisions such as protection from water, ice and debris at stream crossings.
(m) Form coatings and release agents.
(n) Means of obtaining specified concrete.
(o) Location of box outs, pipes, ducts, conduits and miscellaneous inserts in the concrete attached to or penetrating the forms.
(p) Location and spacing of rubber pads where shutter vibrators are used.

5.2 फॉर्म-वर्क / Form-work

- The formwork shall conform to the shapes, lines and dimensions shown on the drawings.
- Formwork shall be so constructed and supported as to remain sufficiently rigid during the placement and compaction of the concrete and shall be sufficiently water-tight to prevent loss of water or mortar from concrete.
- All forms shall be well constructed, carefully aligned, subtle and firm, and securely braced and fastened together in their final position.
- Forms shall be strong enough to prevent the fresh concrete from bulging and withstand the action of mechanical vibrators.
- No surface finishing will normally be provided. Forms for finished surfaces should be smooth and mortar tight. If minor defects are noticed, the surface should be rendered. For major defects, if noticed any repairs should be carried out with prior approval of the engineer.
- The surface may be improved by carefully removing all fins and other projections, thoroughly washing down and then filling the most noticeable surface blemished with a cement and fine aggregate paste.
- No placement shall be done without the approval of the site engineer.
- Forms may be constructed of wood, metal or any other approved material.
- Moulds for pre-tension work shall be sufficiently strong and rigid to withstand, without distortion, the effects of placing and compacting concrete as well as those of prestressing in the case of manufacture by the individual mould process where the prestressing tendon is supported by the mould before transfer.

5.2.1 फॉर्मवर्क की सफाई एवं उपचार / Cleaning and treatment of Formwork

- All rubbish, particularly, chippings, shavings and sawdust shall be removed from the interior of the forms before the concrete is placed.
- The face of formwork in contact with the concrete shall be cleaned and treated with form release agent. Release agents should be applied so as to provide a thin uniform coating to the forms without coating the reinforcement.
- Forms shall not be released until the concrete has achieved a strength of at least twice the stress to which the concrete may be subjected at the time of removal of formwork.

- In normal circumstances where ambient temperature does not fall below 15°C and where ordinary Portland cement is used and adequate curing is done, following striking period may deem to satisfy the guideline given above:

Type of Formwork	**Minimum Period Before Striking Formwork**
a) Vertical formwork to columns, walls, beams	16-24 hrs.
b) Soffit formwork to slabs (Props to be re-fixed immediately after removal of formwork)	3 days
c) Soffit formwork to beams (Props to be re-fixed immediately after removal of formwork)	7 days
d) Props to slabs: 1) Spanning up to 4.5 m 2) Spanning over 4.5 m	 7 days 14 days
e) Props to beams and arches: 1) Spanning up to 6 m 2) Spanning over 6 m	 14 days 21 days

5.3 स्ट्रिपिंग टाइम / Stripping Time

Forms shall not be struck until the concrete has reached a strength at least twice the stress to which the concrete may be subjected at the time of removal of formwork. The strength referred to shall be that of concrete using the same cement and aggregates, with the same propositions and cured under conditions of temperature and moisture similar to those existing on the work. Where possible, the formwork shall be left longer as it would assist the curing.

- In normal circumstances and where ordinary Portland cement is used, forms may generally be removed after the expiry of the following periods:

- For other cements, the stripping time recommended for ordinary Portland cement may be suitably modified.

- The number of props left under, their sizes and disposition shall be such as to be able to safely carry the full dead load of the slab or beam as the case may be together with any live load likely to occur during curing or further construction.

(a)	Walls, columns & vertical faces of all structural members.	24 to 48 hrs. as may be decided by the Engineer.
(b)	Slabs (props left under)	3 days
(c)	Beam soffits (props left under)	7 days
(d)	Removal of props under slabs:	
	(i) Spanning up to 4.5m	7 days
	(ii) Spanning over 4.5m	14 days
(e)	Removal of props under beams:	
	(i) Spanning upto 6 m.	14 days
	(ii) Spanning over 6m	21 days

5.4 तैयार कंक्रीट ब्रिज संरचनाओं के लिए टोलरेंस / Tolerances for Finished Concrete Bridge Structures

1.	Shift from alignment	± 25mm
2.	Deviation from plumb or specified, batter for face of exposed piers.	1 in 250, subjected to a maximum value of 0.05 times the least lateral dimension of pier.
3.	Deviation from plumb or specified, batter for face of backfilled abutments	1 in 125
4.	Cross-sectional dimensions of piers, abutments and girders	-5mm +20mm
5.	Thickness of deck slab of bridges	+6mm -3mm
6.	Size and locations of openings	±12mm
7.	Plan dimensions of footings (formed)	+50mm -25mm
8.	Plan dimensions of footings (Unformed excavations)	+75mm -00mm
9.	Thickness of footings	+No limit -5%
10.	Footing eccentricity	0.02 times the width of the footing in the direction of deviation but not more than 50mm.
11.	Reduced level of top of footing/pier/ bed block	±5mm
12.	Centre to centre distance of pier and abutments at pier top	±30mm
13.	Centre to centre distance of bearings along span	±5mm
14.	Centre to centre distance of bearings across span	±5mm

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Chapter – 6

पूर्वप्रबलन प्रणालियाँ / Prestressing Systems

6.1 पूर्वप्रबल एवं पूर्वप्रबलन बल / Prestress and Prestressing force

The most widely used method for prestressing of structural elements is longitudinal tensioning of steel by different tensioning devices. Prestressing is done by inducing known permanent stresses in a structure or member before the full or live load is applied. These stresses are induced by tensioning the High Tensile Strands, wires or rods, and then anchored to the *member being Prestressed*, by mechanical means.

After prestressing, the concrete shall behave like a member having high tensile strength.

- **Prestress**: Prestress is defined as a method of applying pre-compression to control the stresses resulting due to external loads below the neutral axis of the beam tension developed due to external load which is more than the permissible limits of the plain concrete.

- **Prestressing force**: In prestressed concrete applications, the most important variable is the prestressing force, which remains not constant but reduces with time. During prestressing of the tendons and the transfer of prestress to the concrete member, there is a drop of the prestressing force from the recorded value in the jack gauge. The various reductions of the prestressing force are termed as the losses in prestress.

6.2 पूर्वप्रबलन की सीमाएं / Limitations of Prestressing

- Prestressing needs skilled technology.
- The use of high strength materials is costly.
- There is additional cost in auxiliary equipment.
- There is need for quality control and inspection.

6.3 पूर्वप्रबलित सदस्यों में दबाव / Stresses in Prestressed Members

In determining stresses in prestressed members, the prestressing forces may be treated the same way as other external loads. If the prestress is large enough to prevent cracking under design loads, elastic theory may be applied to the entire concrete cross-section.

For example, consider the simple beam as shown in Fig. (a).

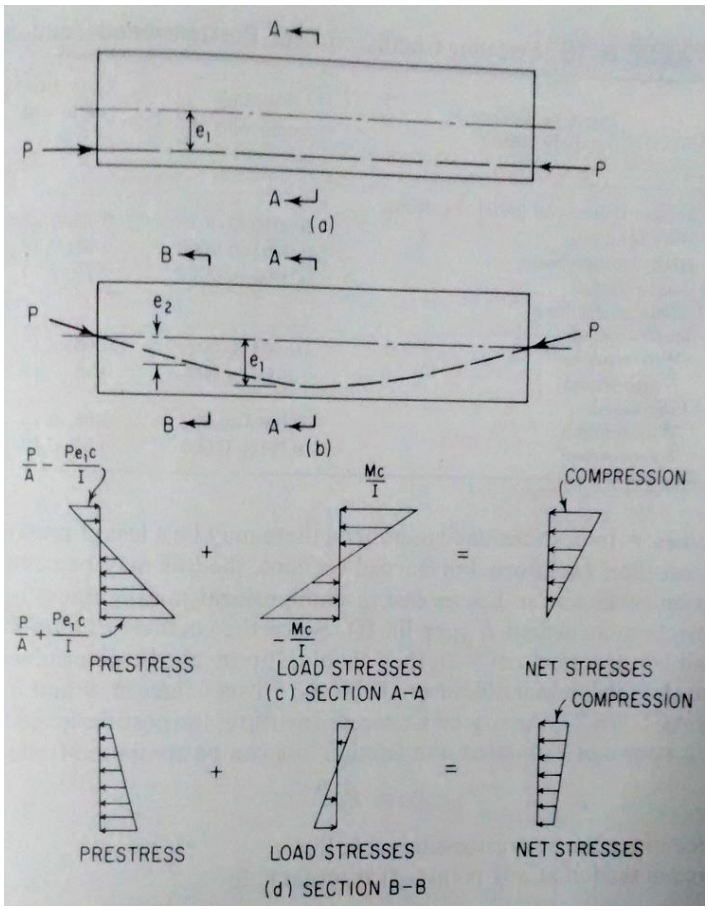
- Prestress P is applied by a straight tendon at a distance e_1 below the neutral axis. The resulting prestress in the extreme surfaces throughout equals $P/A \pm Pe_1c/I$, where P/A is

average stress on a cross section and Pe_1c/I, the bonding stress (+ represents compression, - represents tension), as indicated in Fig. (c).

- If, now, stress ± M_c/I due to downward-acting loads are superimposed at mid-span, the net stresses in the extreme surfaces may become zero at the bottom and compressive at the top (Fig. (c)).

Since the stresses due to loads at the beam ends are zero, however, the prestress is final stress there. Hence, the top of the beam at the ends will be in tension.

If this is objectionable, the tendons may be draped, or harped, in a vertical curve, as shown in Fig. (b). Stresses at mid-span will be substantially the same as before (assuming the horizontal component of P approximately equal to P), and the stress at the ends will be a compression, P/A, since P passes through the centroid of the section there. Between mid-span and the ends, the cross sections also are in compression (Fig. (d)).



6.4 पूर्वप्रबल में हानियाँ / Losses in Prestress

The final pre-compression of the concrete is not equal to the initial tension applied to the tendons. There are **immediate losses**, for example, due to *elastic shortening of the concrete*, *frictional losses from curvature of the tendons*, and *slip at anchorages*. And there are **long-time losses**, such as due to *shrinkage and creep of the concrete* and possibly *relaxation of the steel*.

- These losses should be computed as accurately as possible, determined experimentally, or estimated. They should be deducted from the initial prestress to determine the effective prestress to be used in design.

- One reason high-tensioned tendons are used for prestressing is to maintain the sum of these losses at a small percentage of the applied prestress.

- The prestressing force acting on the concrete differs from the initial tension on the tendons by losses that occur immediately and over a long time.

6.4.1 तात्कालिक हानियाँ / Immediate Losses

- **Elastic shortening of concrete:** In pretensioned members, when the tendons are released from fixed abutments and the steel stress is transferred to the concrete by bond, the concrete shortens because of the compressive stress.

  - In Post-tensioned members, if tendons or cables are tensioned individually, the stress loss in each due to compression of the concrete depends on the order of tensioning. The loss will be greatest for the first tendon or cable tensioned and least for the last one. The total loss may be approximately by assigning half the loss in the first cable to all. As an alternative, the tendons may be brought to the final prestress in steps.
  - In Pre-tensioned Members, when the tendons are cut and the prestressing force is transferred to the member, the concrete undergoes immediate shortening due to the prestress. The tendon also shortens by the same amount, which leads to the loss of prestress.

- **Frictional losses from curvature of the tendons**

  - In Post-tensioned Member, the friction generated at the interface of concrete and steel during the stretching of a curved tendon leads to a drop in the prestress along the member from the stretching end.
  - In Pre-tensioned Members, the loss due to friction does not occur because there is no concrete during the stretching of the tendons.

- **Slip at anchorages**

  - In a post-tensioned member, when the prestress is transferred to the concrete, the wedges slip through a little distance before they get properly seated in the conical space. The anchorage block also moves before it settles on the concrete. There is loss of prestress due to the consequent reduction in the length of the tendon. The total anchorage slip depends on the type of anchorage system.

6.4.2 लंबे समय की हानियाँ / Long-time Losses

- **Shrinkage and Creep of Concrete:**

  - *Losses due to Shrinkage of Concrete*: The deformation which occurs without externally applied stresses is referred to as shrinkage. The shrinkage occurs due to two causes:

    a) Loss of water from voids b) Reduction of volume during carbonation

    The study of shrinkage is also important in prestressed concrete to calculate the loss in prestress. It can be observed that with increasing age at transfer, the shrinkage strain reduces.

As per Clause 5.2.3.1 of IRS Concrete Bridge Code: 1997

- In the absence of test data, the approximate value of shrinkage strain for design may be taken as follows:
  - Total shrinkage strain in plain concrete, reinforced concrete and pre-tensioned prestressed concrete: 0.0003.
- Residual shrinkage strain in post-tensioned prestressed concrete shall be taken as given in table.

AGE OF CONCRETE AT THE TIME OF STRESSING IN DAYS	STRAIN DUE TO RESIDUAL SHRINKAGE
3	0.00043
7	0.00035
10	0.00030
14	0.00025
21	0.00020
28	0.00019
90	0.00015

- *Losses due to Creep of Concrete*: The deformation due to externally applied stress is generally referred to as creep. As long as the stress in concrete does not exceed one-third of characteristic compressive strength, creep may be assumed to be proportional to the stress. Due to the creep of concrete, the prestress in the tendon is reduced with time. It can be observed that
  - If the structure is loaded at 7 days, the creep coefficient is 2.2 (IS 1343: 2012). This means that the creep strain is 2.2 times the elastic strain. Thus, the total strain is more than thrice the elastic strain. Hence, it is necessary to study the effect of creep in the loss of prestress and deflection of prestressed flexural members.
  - Even if the structure is loaded at 28 days, the creep strain is substantial. This implies higher loss of prestress and higher deflection.

Note: Curing the concrete adequately and delaying the application of load provide long term benefits with regards to durability, loss of prestress and deflection.

- **Relaxation of Steel:** When a high tensile steel wire is stretched, and maintained at a constant strain, the initial force in the wire does not remain constant but decreases with time. The decrease of stress in steel at constant strain is termed as relaxation.

The steel in a prestressed concrete member strictly does not remain under a constant condition of either stress or strain. The most severe condition generally occurs at the stage of initial stressing; subsequently the strain in the steel reduces as the concrete deforms under the prestressing force.

Table – 13 Relaxation Losses for Prestressing Steel at1000 h at 20 ± 2°C (Clause 19.5.2.3 of IS 1343:2012)

Sl No.	Initial Stress	Relaxation Loss, Percent	
		Normal Relaxation	Low Relaxation
(1)	(2)	(3)	(4)
i)	0.5 f_p	0	0
ii)	0.6 f_p	3.0	1.0
iii)	0.7 f_p	5.0	2.5
iv)	0.8 f_p	8.0	4.5

NOTE — f_p is the characteristic strength of prestressing steel.

When experimental values are not available, the relaxation losses may be assumed as given in Table – 13 (IS 1343:2012).

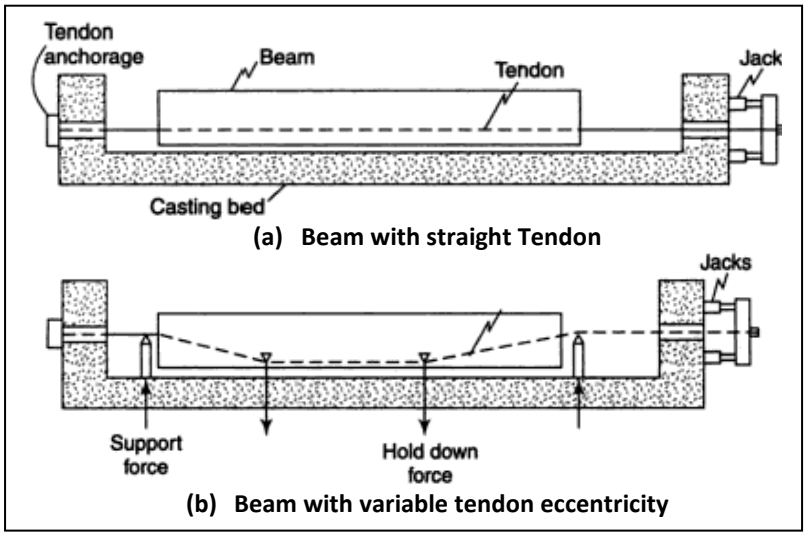
6.5 तनाव उपकरण / Tensioning Devices

Based on Source of prestressing force, the various types of devices used for tensioning steel are as under:

- *Hydraulic*: Simplest type of prestressing, in which hydraulic jacks attached with pressure gauges are used for the tensioning of tendons for producing large prestressing forces.
- *Mechanical*: Adopted for mass scale production, in which devices used includes weights with or without lever transmission, geared transmission in conjunction with pulley blocks, screw jacks with or without gear drives and wire-winding machines.
- *Electrical*: Also known as thermo-electric prestressing, in which steel wires are electrically heated and anchored before placing concrete in the molds.
- *Chemical*: Expansive cements are used and the degree of expansion is controlled by varying the curing conditions.

6.6 पूर्व-तनाव प्रणालियाँ / Pre-tensioning System

In this method, the prestressing steels (tendons) are first tensioned, prior to concreting in the mould, against two rigid anchor-blocks or abutments. The tendons comprising individual wires or strands are stretched with constant eccentricity as shown in (a) or a variable eccentricity as shown in (b) with tendon anchorage at one end and jacks at the other. After achieving required elongation and stresses they are blocked at two abutments and then concrete is poured in the frames with stressed steel in position.



Once the concrete attains the desired strength for prestressing, the tendons are cut loose from the abutments. The prestress is transferred to the concrete from the tendons, due to the bond between them. During the transfer of prestress, the member undergoes elastic shortening. If the tendons are located eccentrically, the member is likely to bend and deflect (camber). For example, manufacture of pre-tensioned electric poles, railway concrete sleepers.

The various stages of the pre-tensioning operation are summarised as follows.

1) Anchoring of tendons against the end abutments
2) Placing of jacks
3) Applying tension to the tendons
4) Casting of concrete
5) Cutting of the tendons.

6.6.1 रंध्र का तनाव / Tensioning the Tendons

- All wires, strands or bars stressed in one operation shall be taken, where possible, from the same parcel.
- Each cable shall be tagged with its number from which the coil numbers of the steel used can be identified.
- Cables shall not be kinked or twisted.
- No strand that has become unravelled shall be used.
- The order in which wires or cables forming a part of prestressing tendon are to stressed should be in such a way that stresses permitted are not exceeded at any stage. The order should be decided by the engineer responsible for the design and should be shown on the working drawings.
- Similarly, where there are a large number of separate tendons, the order in which the tendons are to be stressed should be decided by the engineer and shown on the working drawings.
- The tensioning of each tendon should be such as to cause as little eccentric stress as possible and to ensure this, symmetrical tendons should be successively stressed.

6.6.2 तनाव यंत्र (उपकरण) / Tensioning Apparatus (Devices)

- The requirements of tensioning apparatus shall apply to both the pre-tensioned and the post-tensioned methods of prestressed concrete except where specifically mentioned otherwise.
- Prestressing steel may be tensioned by means of hydraulic jacks of similar mechanical apparatus. The type of tensioning apparatus shall be such that a controlled force can be applied. It shall not induce dangerous secondary stresses or torsional effects on steel, concrete or on the anchorages.
- The means of attachment of the tendon to the jack or tensioning device shall be safe and secure and such as not to damage the wire or bar.
- The force in the tendons during the tensioning shall be measured by direct-reading load cells or obtained indirectly from gauges fitted in the hydraulic system to determine the pressure in the jacks.
- Facilities shall be provided for the measurement of the extension of the tendon and of any movement of the tendon in the gripping devices. The load-measuring device shall be calibrated to an accuracy with +2% and checked at intervals to the approval of the engineer.

Elongation of the tendon shall be measured to an accuracy within ±2% or 2mm, whichever is more accurate.

- The tensioning equipment shall be calibrated before the tensioning operation and at intervals to the approval of the engineer.

Temporary Gripping Device – Prestressing tendons may be gripped by wedges, yokes, double cones or any other approved type of gripping devices. The prestressing wires may be gripped singly or in groups. Gripping devices shall be such that in a tensile test, the wire or wires fixed by them would break before failure of the grip itself.

Releasing Device - The releasing device shall be so designed that during the period between the tensioning and release, the tension in the prestressing elements is fully maintained by positive means, such as external anchorages. The device shall enable the transfer or prestress to be carried out gradually so as to avoid large difference of tension between wires in a tendon, severe eccentricities of prestress or the sudden application of stress to the concrete.

6.6.3 सीधे और विक्षेपित रंध्र / Straight and Deflected tendons

- **Straight Tendons-** In the long-line method of pre-tensioning, sufficient locator plates shall be distributed throughout the length of the bed to ensure that the wires or strands are maintained in their proper position during concreting. Where a number of units are made in line, they shall be free to slide in the direction of their length and thus permit transfer of the prestressing force to the concrete along the whole line.

  In the individual mould system, the moulds shall be sufficiently rigid to provide the reaction to the prestressing force without distortion.

- **Deflected Tendons –** Where possible the mechanisms for holding down or holding up tendons shall ensure that the part in contact with the tendon is free to move in the line of the tendon so that frictional losses are nullified. If, however, a system is used that develops a frictional force, this force shall be determined by test and due allowance made.

  For single tendons, the deflector in contact with the tendon shall have a radius of not less than 5 times the tendon diameter for wire or 10 times the tendon diameter for a strand, and the angle of deflection shall not exceed 15 degrees.

  The transfer of the prestressing force to the concrete shall be affected in conjunction with the release of hold-down and hold-up forces as approved by the engineer.

6.6.4 तार का टूटना / Breakage of Wires

The breakage of wires in any one prestressed concrete member shall not exceed 2.5 percent during tensioning. Wire breakage after anchorage, irrespective of percentage, shall not be condoned without special investigation.

6.6.5 पूर्वप्रबलन बल का स्थानांतरण / Transfer of Prestressing Force

- The transfer of the prestress shall be carried out gradually so as to avoid large differences of tension between wires in a tendon, severe eccentricities of prestressing force and the sudden application of stress to the concrete.
- Where the total prestressing force in a member is built up by successive transfers to the force of a number of individual tendons on to the concrete, account shall be taken of the effect of the successive prestressing.
- In the long line and similar methods of prestressing, when the transfer is made on several moulds at a time, care shall be taken to ensure that the prestressing force is evenly applied on all the moulds and that the transfer of prestress to the concrete is uniform along the entire length of the tension line.

6.6.6 पीएससी स्लीपर के निर्माण में पूर्व-तनाव के तरीके / Methods of Pre-tensioning in Manufacture of PSC sleeper

There are two methods of manufacturing –

Long-Line Method: In Long-line method, moulds are placed on floor in a row. The moulds are stationary, and they do not move in the manufacturing process

- In Long line method, about 40 moulds are placed in a row on shop floor.
- The area required for the shed is very large.
- The mould can be used only once in 24 hours- in one shift, it is cast and in the next shift, it is demoulded and prepared.
- Not very popular due to large area of shed and large number of moulds requirement – large investment.

Stretch Bench Method: The frame that is generally adopted in a pre-tensioning system is called a stress bench. The concrete mould is placed within the frame and the tendons are stretched and anchored on the booms of the frame. In stress Bench method, the moulds are kept in a steel bench. The moulds, along with the steel bench, keep on moving in the manufacturing process.

- Stress bench – 11.5 meters long
- Contains 4 moulds
    - Moulds shall be of steel with minimum plate thickness of 10 mm in Rail seat area as well as for end plates. For other locations, minimum plate thickness is to be 6 to 8 mm.
    - Moulds shall be of rigid construction to prevent any in-service distortions.
    - Moulds shall not allow any appreciable leakage of cement mortar in casting.
    - The holes in the end plates shall be accurately drilled for correct placement of prestressing wires.
- Steel Boxes at ends – one end fixed, other moveable
- Moveable end has 4 bolts

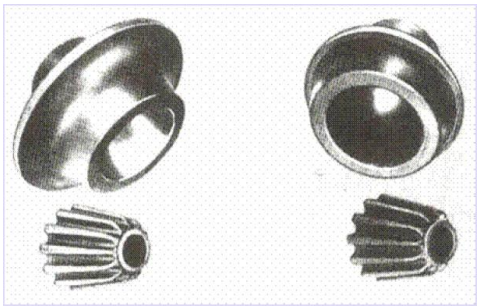
6.7 पश्चात-तनाव प्रणालियाँ / Post-tensioning System

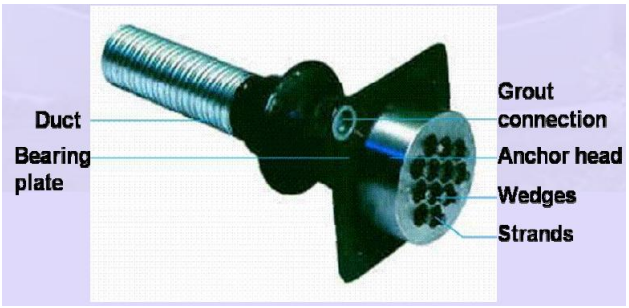
In this method, the prestressing steels (tendons) are stressed after concrete attains its preliminary strength. The concrete units are first cast by incorporating ducts or grooves to house the tendons. After achieving required concrete strength, a stipulated numbers of tendons are inserted in each duct. The tendons are tensioned by means of jack bearing on the end of the face of the member. After achieving required elongation and stresses, they are blocked at two ends with the help of anchor plates and grips (wedge or nuts). The space between the tendons and the duct is generally grouted after the tensioning operation.

Most of the commercially patented prestressing systems are based on the following principle of anchoring the tendons:

- **Wedge action producing a frictional grip on the wire**

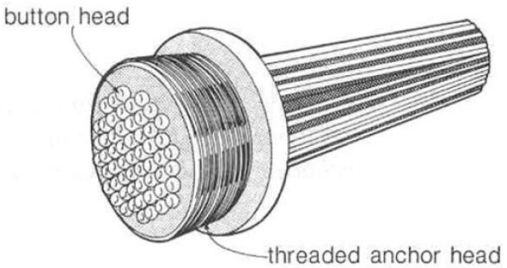
  The anchoring device based on wedge action consists of an anchorage block and wedges. The strands are held by frictional grip of the wedges in the anchorage block. Some examples of systems based on the wedge-action are Freyssinet, Gifford-Udall, Anderson and Magnel-Blaton anchorages. The following figures show some patented anchoring devices.





- **Direct bearing from the rivet or bolt heads formed at the end of the wire**

  The rivet or bolt heads or button heads formed at the end of the wires directly bear against a block. The B.B.R.V post-tensioning system and the Prescon system are based on this principle. The figure shows the anchoring by direct bearing.



- **Looping the wire around the concrete**

  The Baur-Leonhardt system, Leoba system and also the Dwidag single-bar anchorage system, work on this principle where the wires are looped around the concrete. The wires are looped to make a bulb.

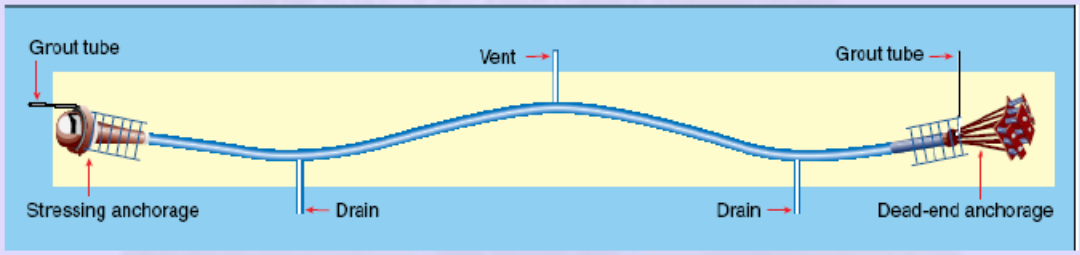
  The photograph shows the anchorage by looping of the wires in a post-tensioned slab.



6.7.1 बंधुआ और बिना बंधुआ बाद-तनाव / Bonded and unbonded post-tensioning

- *If the ducts are filled with **grout**, then it is known as bonded post-tensioning.*
- *In un-bonded post-tensioning, as the name suggests, the ducts are never grouted and the tendon is held in tension solely by the end anchorages.*

The following sketch shows a schematic representation of a grouted post-tensioned member. The profile of the duct depends on the support conditions. For a simply supported member, the duct has a sagging profile between the ends. For a continuous member, the duct sags in the span and hogs over the support.



6.7.2 रंध्रों की व्यवस्था / Arrangement of Tendons

Where wires, strands or bars in a tendon are not stressed simultaneously, the use of spacers shall be in accordance with the recommendations of the system manufacturer.

Deflected Tendons – The deflector in contact with the tendon shall, where possible, have a radius of not less than 50 times the diameter of the tendon and the total angle of the deflection shall not exceed 15 degree. Where the radius is less than 50 times the diameter of the tendon, and the angle of deflection exceeds 15 degree, the loss of strength of the tendon shall be determined by test and due allowance made.

6.7.3 शीथिंग और शीथिंग नलिकाएँ / Sheathing and Sheathing Ducts

A covering that forms an enclosure around the prestressing steel to avoid temporary or permanent bond between the prestressing steel and the surrounding concrete is called sheathing ducts .

- The sheathing ducts shall be either of mild steel or HDPE (High Density Polyethylene).

  - Mild Steel Sheathing:

    i) Unless otherwise specified, the material shall be Cold Rolled Cold Annealed (CRCA) mild steel intended for mechanical treatment and surface refining but not for quench hardening or tempering. The material shall be clean and free from rust and normally of bright metal finish. However, in case of use in aggressive environment (severe and extreme), galvanized or lead coated mild steel strips may be used.

ii) The thickness of the strips shall be a minimum of 0.24 mm ± 0.02 mm for internal diameter of sheathing ducts up to and including 51mm and shall be 0.30 mm±0.02 mm for diameter beyond 51mm and up to 91 mm.
iii) The joints of all sheathing shall conform to the provisions contained in Appendix "C" of IRS Concrete Bride code 1997.

- HDPE (High Density Polyethylene) Sheathing:

i) The thickness of the wall shall be 2.3±0.3 mm as manufactured and 1.5mm after loss in the compression test as per clause B1-2 at Appendix B1 of IRS Concrete Bride code 1997, for sheathing up to 160 mm Outer Diameter.
ii) The sheathing shall be corrugated on both the sides. The sheathings shall transmit full tendon strength from the tendon to the surrounding concrete over a length not greater than 40 times the sheathing diameter.
iii) Sheathings shall be joined by adopting any one of the following methods, as convenient to suit the individual requirements of the location, subject to the satisfactory pressure tests, before adoption.
  - Screwed together with male and female threads.
  - Jointing with thick walled HDPE shrink couplers with glue.
  - Welding with electro-fusion couplers. The joints shall be able to withstand an internal pressure of 0.5 bar (0.05Mpa) for 5 minutes as per water loss test procedure given in clause B-7 at Appendix B of IRS Concrete Bride code 1997.

- They shall be in as long lengths as practical from handling and transportation considerations without getting damaged.
- They shall conform to the requirements as specified in Annexure – B of IS 1343:2012 and a test certificate shall be furnished by the manufacturer.
- The tests specified in Annexure – B of IS 1343:2012 are to be performed as part of additional acceptance tests for prestressing systems employing corrugated HDPE sheathing ducts and are not meant for routine site testing purposes.
- The sheaths shall be sufficiently watertight to prevent concrete laitance penetrating in them in quantities likely to increase friction. Special care shall be taken to ensure water-tightness at the joints.
- The alignment of all sheaths and extractable cores shall be correct to the requirements of the drawings and maintained securely to prevent displacement during placement and compaction of concrete. The permissible tolerance in the location of the sheaths and extractable cores shall be 5 mm. Any distortion of the sheath during concreting may lead to additional friction.

6.7.4 एंकरेज / Anchorages

Anchorages are the means, by which the prestressing force is permanently transmitted from the prestressing steel to the concrete. In post-tensioning applications, a mechanical device comprising all components requires to anchor the prestressing steel and transmits the prestressing force to the concrete.

The anchorage system in general comprises the anchorage itself and the arrangement of tendons and reinforcement designed to act with the anchorage.

- The anchorage may consist of any device patented or otherwise. Proprietary anchorages shall be handled and used strictly in accordance with the manufacturer's instructions and recommendations.
- The anchoring device shall be capable of holding without more than nominal slip the prestressing tendon subjected to a load midway between the proposed initial prestressing load and the ultimate strength of the prestressing tendon.
- The anchoring device shall be strong enough to resist in all respects a force equal to at least the breaking strength of the prestressing tendon it anchors.
- The anchorage shall transfer effectively and distribute, as evenly as possible, the entire force from the prestressing tendon to the concrete without inducing undesirable secondary or local stresses.
- The anchorage shall be safe and secure against both dynamic and static loads as well as against impact.
- The anchorage shall have provision for the introduction of a suitable protective medium, such as cement grout, for the protection of the prestressing steel unless alternate arrangements are made.
- Where embedded anchorage are provided, its spacing, reinforcement details, concrete strength, cover and other dimensions shall conform to the manufacturer's specification/ specialized literature.



Streching and Anchoring Tendons

6.8 तनाव के दौरान सुरक्षा सावधानी / Safety Precautions during Tensioning

- Care shall be taken during tensioning to ensure the safety of all persons in the vicinity.
- Jacks shall be secured in such a manner that they will be held in position, should they lose their grip on the tendons.
- No person shall be allowed to stand behind the jacks or close to the line of the tendons while tensioning is in progress.
- The operations of the jacks and the measurement of the elongation and associated operations shall be carried out in such a manner and from such a position that the safety of all concerned is ensured.
- A safety barrier shall be provided at both ends to prevent any tendon, which might become loose from recoiling unchecked.
- During actual tensioning operation, warning sign shall be displayed at both ends of the tendon.
- After prestressing, concrete shall neither be drilled nor any portion cut nor chipped away nor disturbed, without express approval of the Engineer.

- No welding shall be permitted on or near tendons nor shall any heat be applied to tendons. Any tendon which has been affected by welding, weld spatter or heat shall be rejected.

6.9 ग्रोटिंग संचालन / Grouting Operations

The purpose of grouting is to provide permanent protection to the post-tensioned steel against corrosion and to develop bond between the prestressing steel and the surrounding structural concrete. The grout ensures encasement of steel in an alkaline environment for corrosion protection and by filling the duct space, it prevents water collection and freezing. Grout is a mixture of water, cement and optional materials like sand, water-reducing admixtures, expansion agent and pozzolans. Fine sand is used to avoid segregation.

6.9.1 ग्रोट के गुण / Properties of the Grout

- Water-cement ratio should be as low as possible, consistent with workability. This ratio should not normally exceed 0.45.
- The temperature of the grout after accounting for the ambient temperature of the structure shall not exceed 25 °C.
- Before grouting, the properties of the grout mix should be tested in a laboratory depending on the facilities available.
- The compressive strength of 100 mm cubes of the grout shall be not less than 27 MPa at 28 days.
- Chlorides from all sources, that is, cement, water, sand, fillers and admixture should not exceed 0.1 percent by mass of the cement.

6.9.2 ग्रोटिंग संचालन / Grouting Operations

- Grouting shall be carried out as early as possible, but not later than 2 weeks of stressing a tendon. The sealing of the anchorage ends after concreting is considered to be a good practice to prevent ingress of water. For structures in aggressive environment, sealing of the anchorage ends is mandatory.
- Any traces of oil if applied to steel for preventing corrosion should be removed before grouting operation.
- Ducts shall be flushed with water for cleaning as well as for wetting the surfaces of the duct walls. Water used for flushing should be of same quality as used for grouting. It may, however, contain about 1 percent of slaked lime or quick lime.
- The water in the duct should be blown out with oil free compressed air. As blowing out water from duct for cables longer than 50 m draped up at both ends by compressed air is not effective, outlet/vent provided at or near the lowest point shall be used to drain out water from duct.
- The connection between the nozzle of the injection pipe and duct should be such that air cannot be sucked in.

- All outlet points including vent openings should be kept open prior to commencement of injection grout.
- Before grouting, all air in the pump and hose should be expelled. The suction circuit of the pump should be air-tight.

6.9.3 ग्रोट का इंजेक्शन / Injection of Grout

- After mixing, the grout shall be kept in continuous movement.
- Injection of grout be continuous and should not be interrupted.
- For vertical cable or cables inclined more than 60° to the horizontal, injection shall be effected from the lowest anchorage or vent of the duct.
- The method of injection shall ensure complete filling of the ducts.
- Grouting should be commenced initially with a low pressure of injection of up to 0.3 MPa increasing it until the grout comes out at the other end. The grout may be allowed to flow freely from the other end until the consistency of the grout at this end is the same as that of the grout at the injection end.
- In the case of cables draped downwards for example, in cantilever construction simultaneous injection from both ends may be adopted.
- Grout not used within 30 min of mixing should be rejected.
- Disconnection is facilitated if a short length of flexible tube connects the duct and injection pipe. This may be squeezed and cut off after the grout has hardened.

6.9.4 प्रभावी ग्रोटिंग के लिए सावधानियां और अनुशंसाएं / Precautions and Recommendations for Effective Grouting

- In cold and frosty weather, injection should be postponed unless special precautions are taken.
  - If frost is likely to occur within 48 h after injection, heat shall be applied to the member and maintained for at least 48 h after injection so that the temperature of the grout does not fall below 5 °C.
- When the ambient temperature during the day is likely to exceed 40 °C, grouting should be done in the early morning or late evening hours.
- When the cables are threaded after concreting, the duct shall be temporarily protected during concreting by inserting a stiff rod or a rigid PVC pipe or any other suitable method.
- During concreting, care shall be taken to ensure that the sheathing is not damaged. Needle vibrators shall be used with extreme care by well experienced staff only.
- It is a good practice to move the cables in both directions during the concreting operations.
  - This can easily be done by light hammering the ends of the wires/strands during concreting. It is also advisable that 3 h to 4 h after concreting, the cable should be moved both ways through a distance of about 200 mm.
- The cables to be grouted should be separated by as much distance as possible.
- In case of stage prestressing, cables tensioned in the first stage should not remain un-grouted till all cables are stressed.

- It is a good practice, while grouting any duct in stage prestressing, to keep all the remaining ducts filled up with water containing 1 percent lime or by running water through such ducts till the grout has set. After grouting the particular cable, the water in the other cables should be drained and removed with compressed air to prevent corrosion.

- Care should be taken to avoid leaks from one duct to another at joints of precast members.
- End faces where anchorages are located are vulnerable points of entry of water. They have to be necessarily protected with an effective barrier. Recesses should be packed with mortar concrete and should preferably be painted with water proof paint.
- After grouting is completed, the projecting portion of the vents should be cut off and the face protected to prevent corrosion.

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परिशिष्ट / Annexure -1

फॉर्म A - प्रथम चरण पूर्वप्रबलन / Form A – 1st Stage Prestressing

NAME OF THE FIRM:……

STRESSING OF ……..M LONG ……..(DIV) P.S.C. GIRDER

PROJECT : …… Date:…… CH:……

GIRDER DETAILS

Span No…… Girder No…….. Cable No…… Type: ……..

Concreted on …… Cube Strength…… Any Cracks: Yes/No

MATERIAL/EQUIPMENT DETAILS

H.T. Steel:

(1) Coil No……. (2) A (Actual) = ……. (3) E (Actual) = …….

(4) Test Report No…… (5) A (Theoretical) =……. (6) E (Theoretical) = ……

Sheathing: (1) Internal Dia. = …… (2) Damages: ……..

Jacks: (1) No. (1): …… (2) No. (2): ……..

(2) Ram area = ……. (2) Ram area = …….

(3) Efficiency = ……. (3) Efficiency = …….

(4) Pump No. = …….. (4) Pump No. = ……..

(5) Pressure Gauge No. …… (5) Pressure Gauge No. ……

(6) Locking Pressure …… (6) Locking Pressure ……

DATA REQUIRED FOR STRESSING

1 (a) Jacking Force in Cable as per Standard drawing =…… (b) Jacking Pressure = 1(a)/Efficiency X Ram Area =…...

2(a) Theoretical Elongation as per Standard drawing = …… (b) Modified Elongation = $\frac{2(a) \times A (Th.) \times E (Th.)}{A(Actual) \times E (Actual)}$ =…...

3 (a) Limits of Jacking Pressure (± 5% of Required Pressure) = …….. To ……..

(b)(a) Limits of Modified Elongation (± 5% of Required Elongation = …….. To ……..

4 (a) Reduction in length of wire Inside Jack during Release = $\frac{\text{Jacking Pressure X Length of wire inside jack}}{E (Actual)}$ = ……

(b) Actual Permissible Slip at Each End = 4(a) + 6.00 mm= …….

(c) Total Permissible Slip = 2 X 4(b) = …….

STRESSING RECORD

JACK Pressure	X End			Y End			Remark, if any
	Reading	Difference	Zero correction	Reading	Difference	Zero correction	
Reading before locking (A)							
Reading after locking (B)							

Calculations:

Description	X End	Y End	Remark, if any
Actual Elongation before Locking (C) = (A) – Zero Correction			
Slip = (A) – (B)			
Net Elongation = (C) - Slip			

Result:

1. Final Jack Pressure = …….
2. Final Elongation = …….
3. Slip (a) At X End = ……. (b) At Y End = …….. (C) Total Slip = ……

Conclusion:

1. Jack Pressure lies within limits of ……. to ……..
2. Net Elongation lies within limits of …… to ……..
3. Total Slip of …… mm is less than permissible slip of ……. mm.
4. Hence prestreesing is Satisfactory / Not Satisfactory.

Contractor **SSE/JE** **XEN**

परिशिष्ट/ Annexure - II

पीएससी निर्माण में गुणवत्ता नियंत्रण के लिए चेकलिस्ट / Checklist for Quality Control in PSC Construction

S. No.	Points to be checked
A	**Organization for Quality Control**
i)	Headed by Quality Control in-charge who should be graduate with Civil Engineering Degree
ii)	Store in charge with Diploma in Civil Engineering, or equivalent
iii)	Quality Control Supervisor for laboratory & testing - Minimum one supervisor with Diploma in Civil Engineering
iv)	Shift in-charge for production - One supervisor with Diploma in Civil Engineering - Per shift per casting location
v)	Machine in-charge - One supervisor with diploma in Mechanical Engineering for maintenance of plants and equipments
B	**Storage requirement for Quality Control of Material**
i)	Cement go-down - Cement should be stored as mentioned in Para 3.5.1
ii)	High Tensile Steel - Storage as per Para 4.4
iii)	Insert go-down
iv)	Steam curing chambers for curing of precast members
v)	Submerge water curing tank
vi)	Stocking area for finished production
vii)	Laboratory - General – approx 40 sqm - Product testing area – approx 30 sqm
vii)	Inspecting officials office - Min 25 sqm
C	**Plant & Machinery for Quality Control in Production**
i)	Concrete mixture with automatic batching plant using microprocessor based weight batcher, pneumatic operated aggregate with water meter and automatic cement feeding
ii)	Standard weights of 50 kg & shall be capable of measurement to the least count of 1 kg for calibration of weight batcher
iii)	Water measuring cane or automatic water meter for calibration of water meter
D	**Laboratory equipments for testing of material & finished products**
1.	Compression testing machine [2000 KN capacity], motorized with 2 nos. of pressure gauge [2000 KN & 500 KN] with digital interface for real time recording of testing results
2.	15 cm cube moulds conforming to IS: 516
3.	Flexure beam [tension] testing machine if required
4.	Beam moulds 10X10X50 cm size
5.	Universal testing machine for testing of HTS wires 100 KN capacity

6.	Slump Tester/Vee Bee Testing Machine – 1 No.
7.	Electronic balance with 1gm least count (10 / 20 Kg capacity) including weights. – 1 No.
8.	Blain's air permeability apparatus – 1 No.
9.	Vicat apparatus with dash pot and various needles – 1 No.
10.	Stop watch – 1 No.
11.	Le Chatelier mould for soundness test of cement – 1 No.
12.	Steel trowels for mixing cement paste – 2 No.
13.	Cement mortar cube casting machine with motor and time switch complete – 1 No.
14.	7.06 cm (50 cm^2) mortar cube moulds
15.	Electronic Platform balance with 200 kg capacity – 1 No.
16.	Metallic scoop, pan type container and china tray etc. – 2 Sets
17.	Aggregate Impact testing machine – 1 No.
18.	Aggregate crushing testing machine – 1 No.
19.	Aggregate Abrasion testing machine – 1 No.
20.	Electric thermostatic oven with display of temperature – 1 No.
21.	Set of IS Sieves 40 mm and below up to 75 micron – 1 No.
22.	Automatic electric sieve shaker – 1 No.
23.	Proving rings of 2000 KN, 500 KN, and 100 KN capacity – 1 Each
24.	Motorized pumping unit with 500 KN capacity jacks, pressure gauge, rubber tubes and test frame complete for sleeper testing. The digital display of the load applied should be visible to observer simultaneously along with observation of crack. The data shall be recorded in computer with automatic date and time record with Batch no. and other detail for traceability of record. – 1 No.
25.	1.5 Volt AVO meter – 1 No.
26.	Glass cylinders and Beakers 50 - 500 cc capacity – 1 Set
27.	Miscellaneous measuring gadgets like steel tape, Vernier, filler gauge etc. – 2 Sets
28.	VOGT type rope tensometer up to 9.5 mm dia wire – 1 No.
29.	Inspection gauges for dimension checking of sleepers with digital display of parameters as approved by RDSO – 2 Sets
30.	Master gauges for checking inspection gauges – 1 Set
31.	Magnifying glass – 1 No.
32.	Level table steel for checking gauges – 1 No.
33.	pH meter & TDS meter (Digital) – 1 No.
E	**Material testing record for Quality Control of Material**
I	Cement
a)	Cement brand
b)	Location of cement plant
c)	Test certificate from manufacture for each batch should be kept in record
d)	Cement should confirm to provisions of Para 3.5.1
II	HTS wire
a)	BIS approved source
b)	Validity of BIS approval
c)	Conforming to IS: 6006 specification
d)	Type (Plain, Strand) : Nominal Dia.
e)	Breaking load & elongation – 0.2% proof stress

f)	Young's Modulus
g)	Test certificate from manufacturer for each coil should be kept in record
h)	Storage of prestressing steel
III	HYSD/Mild Steel
i)	Mild steel should conform to IS: 226 & IS: 432
ii)	HYSD bars should conform to IS: 1786
IV	Coarse aggregate
i)	Conform to IS:383-1970 (Re-affirmed 2002)
ii)	Satisfy provisions of Para 3.5.2
iii)	Record of sieve analysis
V	Fine aggregate
i)	Conform to IS:383-1970 (Re-affirmed 2002)
ii)	Satisfy provisions of Para 3.5.2
iii)	Record of sieve analysis
VI	Mix Design
i)	Mix design shall be based on IS: Method as given in IS: 10262-2009 - In specifying particular grade of concrete, the following information shall be included a) Grade designation, b) Type of cement, c) Maximum nominal size of aggregates, d) Minimum cement content (for design mix concrete), e) Maximum water-cement ratio, f) Workability, g) Exposure conditions, h) Maximum temperature of concrete at the time of placing, j) Method of placing, and k) Degree of supervision.
ii)	Report of Mix Design from a Reputed Institute / Lab along with details of receipt, source, date of receipt, truck no., quantity, balance, remark about quality and signature for the following shall be kept in record: (a) Coarse Aggregate (CA1) 20 to 100mm (b) Coarse Aggregate (CA2) 10mm & below (c) Fine Aggregate (Sand)

***

संदर्भ / REFERANCE

1.	IS 456 : 2000 Plain and Reinforced Concrete – Code of Practice (Fourth Revision)
2.	IS 1343 : 2012 Prestressed Concrete – Code Of Practice (Second Revision)
3.	IS 10262 : 2009 Concrete Mix Proportioning – Guidelines (First Revision)
4.	IS 6006 : 1983 (Re-affirmed 2008) Specification For Uncoated Stress Relieved Strand for Prestressed Concrete
5.	IS 1785(Part 1) : 1983 (Re-Affirmed 2008) Specification for Plain Hard-Drawn steel Wire for Prestressed Concrete
6.	IS 2090 : 1983 (Re-Affirmed 1989) Specification for High Tensile Steel Bars used in Prestressed Concrete
7.	INDIAN RAILWAY STANDARD – Concrete Bridge Code - September 2014 (Incorporating A&C 1 to 13 and Incorporating up to CS-3 dtd 20.1.15)
8.	CONCRETE TECHNOLOGY (Corrected & Reprinted : January 2014) (www.iricen.gov.in)
9.	Prestressed Concrete by N Krishna Raju - McGraw Hill Companies - 4th Edition
10.	Prestressing Manual (www.freyssinet-india.com)
11.	Indian Railway Standard Specification for Pre-Tensioned Prestressed Concrete Sleepers for Broad Gauge and Metre Gauge [Serial No. T-39 (Fifth Revision –February 2016)]

***

टिप्पणी / NOTES

गुणवत्ता नीति

रेलों में यात्री और माल यातायात की बढ़ती माँग को पूरा करने के लिए गुणवत्ता प्रबंध प्रणाली में अनुसंधान, डिज़ाइनों और मानकों में उत्कृष्टता तथा सतत सुधारों के माध्यम से सांविधिक और नियामक अपेक्षाओं को पूरा करते हुए सुरक्षित, आधुनिक और किफ़ायती रेल प्रौद्योगिकी का विकास करना।

QUALITY POLICY

To develop safe, modern and cost effective Railway technology complying with Statutory and Regulatory requirements, through excellence in Research, Designs & Standards and Continual improvements in Quality Management System to cater to growing demand of passenger and freight traffic on the Railways.

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हमारा उद्देश्य

अनुरक्षण प्रौद्योगिकी और कार्यप्रणाली को उन्नयन करना तथा उत्पादकता और रेल्वे की परिसंपत्ति एवं जनशक्ति के निष्पादन में सुधार करना जिससे अन्तर्विषयों में विश्वसनीयता, उपयोगिता और दक्षता प्राप्त की जा सके।

यदि आप इस संदर्भ में कोई विचार और सुझाव देना चाहते हों तो कृपया हमें इस पते पर लिखें।

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Our Objective

To upgrade Maintenance Technologies and Methodologies and achieve improvement in productivity and performance of all Railway assets and manpower which inter-alia would cover Reliability, Availability, and Utilisation.

If you have any suggestion & comments, please write to us:

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