Odisha Integrated Irrigation Project for Climate Resilient Agriculture (OIIPCRA)

FIELD HAND BOOK

QUALITY CONTROL & QUALITY ASSURANCE
CONSTRUCTION PROCEDURES & NORMS

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Background:

Government of Odisha is implementing the World Bank supported Odisha Integrated Irrigation Project for Climate Resilient Agriculture (OIIPCRA) through the Department of Water Resources (DoWR). The Govt. of India in the Department of Economic Affairs (DEA), in the Ministry of Finance, has approved the OIIPCRA on 23.2.2017. The cost outlay of the project is US$ 235.54 Million (Rs. 1,683 Cr) out of which US$ 165.00 Million (Rs. 1,179 Cr) is funded through World Bank (IBRD Loan) assistance at 70:30 (Centre: State) cost sharing. The period of implementation of the project is 6 Years from 2019-20 to 2024-25.

The project is being implemented through the "Odisha Community Tank Development & Management Society (OCTDMS)", a Special Purpose Vehicle (SPV) created under the Department of Water Resources (DoWR), Government of Odisha. 538 Nos. of Minor Irrigation projects have been identified for rehabilitation in 4 river basins e.g., Rushikulya, Budhabalang, Baitarani and Tel Sub-basin covering about 56,200 Ha in 15 Districts of Odisha which include Bolangir, Balasore, Bargarh, Bhadrak, Boudh, Gajapati, Ganjam, Jajpur, Kalahandi, Keonjhar, Mayurbhanj, Nabarangpur, Nuapada, and Subarnapur.

Project Objectives

One of the objectives of the project is to improve and ensure the water availability for irrigation applying a number of efficient water use and water conserving systems. This includes rehabilitation and restoration of minor irrigation tanks. Majority of rehabilitation works include civil works such as strengthening of tank embankment, strengthening of tank structures, repair and restoration of distribution system, construction of feeder channel and field channels, Implementation of Dam Safety Expert Panel recommendations.

Government of Odisha is committed to deliver quality construction through a determined project team and contractors to create a successful project while implementing the works for improved and ensured water delivery responsibilities. Hence, it is imperative that, the field functionary needs to be acquainted with the quality observance systems.

Quality of construction wholly depends on workmanship during construction. Only the use of best suited material cannot ensure the quality of construction. It needs care and proper selection of materials, methods and timely application of suitable processes.

Quality Assurance is the pre-processes or precautions taken before or during construction which assures a quality construction with minimized errors and excuses. Quality assurance during execution of civil works plays an important role in achieving efficient results under the given conditions and circumstances. This saves a lot of effort and money which otherwise will lead to loss of desired outcome and even loss of life.

Quality Control is the methods or techniques that need to be acted upon during construction to fulfill or control the errors that may lead to produce a defective construction which may not be safe for use or sustain for desired output effectively. Sometimes it may necessitate a demolition of such structures constructed due to its bad quality.

In addition, capacity building of the Project/ Department staff to assess, maintain and ensure the quality of civil works and the safety of the projects is also essential for future sustainability. To ensure that there are no compromises on quality in civil works, and no slippages in processes, it is necessary to educate, familiarize the processes related to maintain the quality of the civil works and ensure the quality of works to meet agreed designs and specifications to the workforce involved in execution of these works.

Quality Control & Quality Assurance is a joint responsibility exercised during construction planning and construction itself. These include:

- Identification and use of right kind of construction materials and methods through a set of standard procedures of testing or ensuring for desired output.
- Identification of most suitable and economical construction equipment that is best suited for achievement of economical construction, speed, quality and workmanship.
- Adoption of OK card system which ensures overlook of intermediate processes for safely completion of the construction.

This will enhance the competence for methodical execution of works and make the practitioner achieving in preventing problems to occur, correct them swiftly if they occur and stop recurrence of any problems.

This hand book includes such essential procedures and guidelines to be observed in the field for easy understanding of the project execution and **Quality Control & Quality Assurance** by the field personnel.

1.0 ROUTINE FIELD TESTS OF BUILDING MATERIALS FOR QUALITY

1.1 Building Materials

Selection of building materials are made on its versatility of its use, its physical and chemical properties to mix up in conjunction with other ingredients and its durability in wear and tear along with its availability at economic considerations. Scientists and building engineers after several tests and practices have specified the use of certain materials for building construction. Indian Standards Organisation has recommended some specifications and prescribed laboratory and also some field tests for these materials before use in different type of construction.

As for the general knowledge's sake of the many engineers of the department who have been engaged in construction, the practices in identifying the deficiencies in the construction materials need regular update of their knowledge. The following field test methods of the building materials will refresh and remind them during the practice of engineering.

The following are the building materials being encountered in normal civil engineering constructions:

i. Fine Aggregate (Sand)
ii. Coarse Aggregates (Chips, Metal)
iii. Soil (for embankments, foundation)
iv. Cohesive Non-Swelling soil (Moorum, gravel)
v. Cement
vi. Water
vii. Reinforcement Steel

1.2 Field Tests for Fine Aggregate (Sand)

Sand is an important ingredient acting as a filler material employed in concrete to fill out the pores between cement and coarse aggregates for the reduction of segregation. This makes the concrete more compact and thereby improve the bonding strength between the ingredients in Cement Concrete. It needs to be free from impurities like silt or clay or otherwise the presence of silt or clay should be within the permissible limits which shall be below 5%. Crushed sand is preferred over natural sand as having better structural properties than natural sand which normally have less impurities such as silt or clay.

1.2.1 Sand is categorized in to three types according to its use;

i. for filling in foundation,
ii. Used as an ingredient in cement mortar and cement concrete
iii. As filter material

For the first type of use as filling material in foundation, generally no testing is being conducted except for its silt content on simple eye inspection. For the second type of use, a number of tests are conducted and checked for compliance to different specifications for its specific uses as under:

a) Grading of sand and fineness modulus
b) Silt content and other impurities (for natural sand)
c) Bulkage of moist sand
d) Organic impurities

1.2.2 Grading and Fineness modulus of sand

Sand having grain size more than 75 micron is suitable for use in cement mortar or cement concrete. Grading of sand determined by sieving through a set of sieve sizes of 75-micron, 150-micron, 300-micron, 600-micron, 1.18 mm, 2.36 mm and 4.75 mm as per Indian Standard Practice Code IS-383:1970 – Specification for coarse and fine aggregates from natural sources for concrete.

1.2.2.1 Test Procedure for grading: Air dried sample of 3 Kg (3000 gram) is placed on the 4.75 mm sieve at the top on the set of sieves with 75-micron sieve in the bottom and sieved by shaking in circular, forward or left to right motion for atleast 2 minutes. Smooth brushes may be used to remove the finer soils clogged in the 150- or 75-micron sieves.

Table 1.1

IS Sieves	Weight Retained in gram	Percentage Retained	Cumulative % Retained	Percentage Passed
4.75 mm	12	0.40	0.40	99.60
2.36 mm	270	9.00	9.40	90.60
1.18 mm	480	16.40	25.40	74.60
600 microns	989	41.97	58.37	41.63
300 microns	854	44.87	86.83	13.17
150 microns	350	53.63	98.50	1.50
Pan	45	-	-	-
Total	**3000**		**278.90**	

The amount of sand remained in each of the sieves after sieving is weighed as quantity retained in the respective sieve (a sample sieving test values is tabulated as in Table 1.1). The values in right most column i.e., "Percentage of Passing" is compared to the table of grading as per IS-383 reproduced here as under in Table 1.2 to obtain the grading of the sand.

Table 1.2

IS Sieves	Percentage Passing in different Zones			
	Zone-I	Zone-II	Zone-III	Zone-IV
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 microns	15-34	35-59	60-79	80-100
300 microns	5-20	8-30	12-40	15-50
150 microns	0-10	0-10	0-10	0-15

Note: Sand coming under Zone-IV is not suitable for reinforced cement concrete works.

The Fineness Modulus (FM): Percentage of the total of the values of cumulative % retained (Refer Total of Column-4 in Table 1.1) i.e., **278.90/100 = 2.79**

Only sand between **FM 2.6 to 2.9** is considered suitable for **nominal mix** proportion.

Combining of fine Aggregate on the basis of FM

The number of parts of fines and to be mixed with part of a coarse sand in order to obtain a sand of desired FM (say Fr) could be determined approximately by the formula: $\frac{Fr-FF}{FC-Fr}$

Where, FC and FF are the Fineness Moduli (FM) of coarse and fine sand respectively and 'Fr' is the required or desired FM of the mix.

The following Table 1.3 indicates the type of sand for different uses:

Table 1.3

Type of Sand	Fineness Modulus Value	Specific Uses
Very fine sand	Below 2.2	Plastering
Fine sand	2.2 to 2.6	Plastering
Medium sand	**2.6 to 2.9**	**Nominal Mixes**
Coarse sand	2.9 to 3.2	Design Mixes
Very coarse sand	Above 3.2	Mass Concrete

1.2.3 Silt content and other impurities in sand

Silt or clay presence in sand will impair the binding strength produced by sand in cement mortar or cement concrete. IS code prescribed the presence of clay or silt in sand to be limited to less than 5% for use in cement mortar or concrete.

1.2.3.1 Test procedure for Silt content and other impurities in sand

Method-1: The apparatus required for this test is only 250 ml glass measuring cylinder.

The silt content determination by volume is done in the following manner:

i. The glass cylinder is filled with salt-water solution (concentration of the solution with teaspoon full of common salt for every 570 ml) upto 50 ml mark.
ii. Add sand until the level of the water solution is upto 100 ml mark.
iii. Add further salt-water solution till 150 ml mark is reached.
iv. Place the palm on the mouth of the glass cylinder and shake it vigorously.

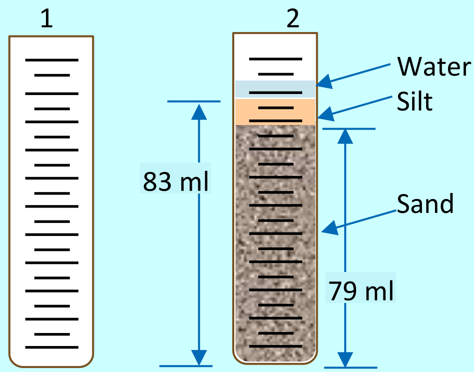
v. Place the cylinder on hard levelled surface and tap it all round so that sand is leveled.
vi. Wait for three hours for silt to settle on top of sand.
vii. Measure the thickness of the silt layer and the height of the sand. The silt content can be calculated as follows:

Silt (%) by volume = [Height of silt layer/ (Height of sand + Silt)] x 100 %

Method-2: Take 100 gram of sand in a 100 ml capacity graduated glass or plastic jar/cylinder. Add clear water so as to totally submerge the sand and a little over it up to 85 ml mark in the jar. Then shake the jar vigorously to wash the sand in the jar and keep aside. Add 10 ml of 10% alum solution to the water in the jar. Keep the set undisturbed for 24 hours which will allow the silt if any to settle and deposited over the sand in the jar. Measure the height of sand column and silt/clay layer.

For example, if the depth of silt/clay layer is at 83 ml mark and sand is at 79 ml mark, then the silt/clay content is 100*(83-79)/83 = 4.82% which is within the permissible limit.

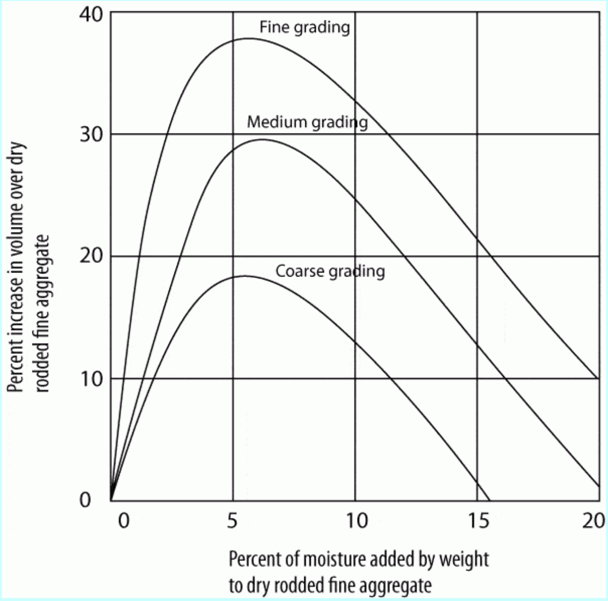
Note: If silt content by weight exceeds 3% then washing of sand is necessary. After conducting few tests, a co-relation can be developed for silt layer thicknesses at various intervals of time. The silt content at 10 minutes can be fixed as inspection criteria.



1.2.4 Bulkage of moist sand

Bulking of sand test depends on the fact that the dry volume of sand and saturated volume of sand has almost the same volume.

When sand is moist, its volume increases due to the act of surface tension in the water layer covered around the surface of sand particles. That means while measuring the sand in terms ratio by volume to the cement, there is a lesser volume of sand against the actual volume or in other way, there is high content of cement to sand ratio. This will also lead to high water to cement ratio which may indicate a higher slump and may be concrete would not be suitable for the purpose for which it is prepared. The permissible bulkage is 20%.



1.2.4.1 Test procedure for Bulkage of moist sand

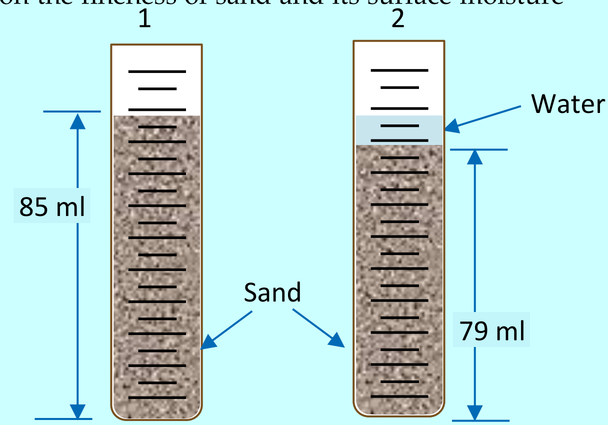
Take some amount of sand and pour into the graduated glass/ plastic cylinder and fill it to say 85 ml (H) mark (pic-1). Then pour clear water slowly to submerge the sand completely and shake/ tap the jar/ consolidate the sand by pushing by a glass rod so as to remove any entrapped air/water bubble from the sand. Allow it to stand for atleast 30 minutes and measure the new level of sand which have gone down from its previous level, say it is now 79 ml mark (pic-2).

Bulking is calculated as: **Bulking % = h/H x 100%.**

The Bulkage of sand will be computed as under: [(85-79)/85] *100 = 7.06%. As the bulkage is within 20% it is acceptable, however, this bulkage has to be compensated by adding the same amount of more sand (in this case 7.06%) and reduce same amount of water which otherwise affect the water cement ratio.

Dry sand occupies the same volume as fully saturated sand. Only the presence of moisture makes it to bulk or expand its volume. The bulking varies from load to load and day to day depending on the fineness of sand and its surface moisture content.

It is there-fore, very essential to make bulking corrections by checking the actual bulking of sand proposed to be used by volumetric batching for mortar or concrete. Hence, it's better to adopt weigh batching over the volume batching by knowing the moisture content.



1.2.5 Organic impurities

Harmful chemicals mixed in sand may impair the quality/ strength/ induce early rusting of reinforcement within the concrete or discoloration in the walls.

1.2.5.1 Test for chemical/organic impurities in sand

In a 350 ml capacity glass/plastic jar take about 75 ml of 3% solution of caustic soda . Then pour the sand to be tested gradually into the jar to the level of 125 ml mark. Then add more 3% solution of caustic soda (NaOH- Sodium Hydroxide) up to the level of 200 ml mark. Then close the jar with stopper and shake it vigorously and keep aside undisturbed for 24 hours. Then observe the colour of the liquid in the jar:

i. a clear colour indicates, no impurities in the sand (sand is OK);
ii. a straw colour indicates presence of non-objectionable organic impurities (sand is OK);
iii. a dark colour indicates presence of harmful chemical impurities in the sand (it should be washed thoroughly and re-tested for acceptance before use.)

1.3 Field Tests for Coarse Aggregate (Metal, Chips)

The field tests for coarse aggregate are limited to its grading to find out its suitability for specific uses such as, mass concrete, column or beams, reinforced concrete in roof slabs etc.

The recommended percentage of different nominal coarse aggregate sizes for different mix specifications is provided in the Table 1.3.

Table 1.3

Recommended % of Passing for graded Coarse Aggregates			
FA / IS Sieves	**CA 40 mm**	**CA 20 mm**	**CA 12.5 mm**
80 mm	0.00	0.00	0.00
40 mm	95-100	0.00	100.00
20 mm	30-70	95-100	90-100
10 mm	10-35	25-55	40.85
4.75 mm	0-5	0-10	0-10
2.36 mm	-	-	-

The grain size or grading is done as explained for fine aggregates in paragraph 1.2.2 above but with the following sieve sizes: 63 mm, 40 mm, 20 mm, 16 mm, 12.5 mm, 10 mm, 4.75 mm and 2.36 mm. The size of sample coarse aggregates may be taken is 5.0 Kg.

1.4 Field Tests for Soil

Field tests for Soil are less precise than laboratory tests for determining engineering properties, but they better represent the in-situ soil character. Field tests for Soil can be collected at targeted points and yield data more quickly than laboratory testing.

Field testing methods are most likely to be used for the determination of the engineering behavior of soils and rocks in which it is difficult, impossible or very expensive to obtain good quality undisturbed samples for laboratory tests.

However, the most common field test carried out is the determination of moisture content. This is required to compare with the dry density and to obtain the Optimum Moisture Content (OMC) during consolidation of soil in embankments. The test is done in the following two methods:

i. **Conventional Method:** a small quantity of soil sample is taken in a container and weighed as Ws. Then the container along with the soil sample is heated in a low fire or by driers. After drying, the container along with the dried soil sample is weighed as Wd. The weight of the container is taken as Wc. Now, the weight of the dry sample is Wd-Wc and weight of the moisture present in the soil is Ws-Wd.

Hence, the moisture content of the soil = Weight of Moisture/Dry Weight of soil or = [(Ws-Wd)/(Wd-Wc)] *100%

ii. **Using Rapid Moisture Meter:** Rapid Moisture meter uses Calcium Carbide which reacts with water (moisture) to form Acetylene gas and vapourises the water. The quantity of gas produced puts on pressure inside the bottle which is indicated through a pressure gauge fitted in the container bottle in which the soil sample is tested. A soil sample of 6 grams is weighed and taken in the pressure bottle of the moisture meter. A pinch of calcium carbide is put in that bottle and shaken to mix with soil.

After a minute of reaction of calcium carbide with the moisture in the test soil sample, the pressure rises in the bottle which is shown in the pressure gauge fitted with the bottle in percentage. If the pressure is say ‘w’, then the weight of the dry soil will be 100-w. So, the moisture content will be computed as [w/(100-w)] *100%.

1.5 Field Tests for Cement

Quality tests on cement at the construction site are performed to know the quality of the cement supplied, within a short amount of time. It is not possible to have laboratory tests done in the short period of time, hence in such times the basic field Tests for Cement are done on the cement to check its quality. These tests give some idea about the quality of the cement. Detail specification for testing of cement may be referred to IS 650:1991 Specification for standard testing of cement.

- i. Color test
- ii. Presence of lumps
- iii. Adulteration test
- iv. Temperature test
- v. Float tests
- vi. Setting test
- vii. Strength test
- viii. Date of Packing

1.5.1 Color Test of Cement

The typical colour of the cement should be grey with a light greenish shade. This colour should be uniform.

1.5.2 Presence of Lumps

Due to the moisture from the atmosphere, cement develops lumps. But it's not good to use that for construction. A sample of 500-gram cement opened from the bag should be sieved in a 600-micron sieve. No lumps should be remained in the sieve. Any bag which is delivered to the site with lumps should be rejected.

1.5.3 Adulteration Test

This test is performed by feeling the cement with fingers. It should feel smooth when rubbed in between fingers. If it feels rough, it implies that the cement is adulterated with sand or coal ash.

1.5.4 Temperature Test of Cement

This test involves inserting the hand in the bag to check its temperature. It should be cool inside. If it's warm inside, then it indicates that the process of hydration has taken place.

1.5.5 Float Test

This test consists of throwing some handful of cement in the bucket full of water. The cement particles should float for some time before sinking.

1.5.6 Setting Test

In this test, a thick paste is prepared by mixing cement and water and is placed on a piece of glass plate for 1 hour. This is then kept under water for 24 hours. After this, it should set and not crack by pressing with fingers.

1.5.7 Strength of Cement Test

This test involves preparation of a block of cement of dimension 25 mm ×25 mm and length of 200 mm. It is immersed for 7 days in water. It is then placed on supports 150mm apart and it is loaded with a weight of about 34kg. If the block will not show any failure, then the cement is of good quality.

But if you don't have such types of arrangements then do the next process. Again, make a block of mortar having cement, the sand ratio (1:6) of dimension 75 mm x 25 mm x 12 mm. Immerse it in water for three days without disturbing.

After three days remove it from water and dry it for an hour and check the sound by hammering slowly with your finger or rocks. If there are quality sounds like metallic then the cement is considered to be good.

1.5.8 Date of Packing

Strength of cement reduces with time, so it is important to check the manufacturing date of the cement. The general fact is that the cement should be used before 90 days from the date of manufacturing which normally provides 70-80% of its designated strength. Manufacturers never indicate the expiry date; instead, they only indicate the date of manufacture and are written in **black ink** in the format Date … Week… Month… Year e.g., **D17 W46 M11 Y21** or simply written **17 46 11 21**. This implies that, the cement is manufactured on **17^{th} November 2021**. There is an additional date information of confirmation of the date of manufacture by indicating the 46^{th} week over and above the month as 11^{th} (46^{th} week is coming in November; week is counted from 1^{st} of January).

1.6 Tests for Water

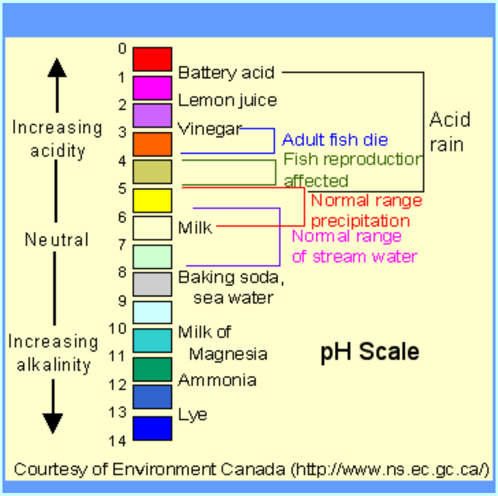
Any natural water that is potable and has no pronounced taste or odour is satisfactory as mixing water for making in cement concrete. However, water used for both mixing and curing shall be free from injurious amounts of deleterious materials. When we prefer the term potable water then it means that water which is safe for drinking and free from high level quantities of alkalis, acid, oils, salt, sugar, organic materials, vegetable growth and other substances. The quality of water is ascertained by the following two methods:

i. The average 28 day's compressive strength of at least three 15 cm concrete cubes prepared with water to be used shall not be less than 85% (as per IS 456-2000) of the average strength of three similar concrete cubes prepared with distilled water.

ii. The initial setting time of test block made with the proposed cement and water to be used shall not be less than 30 minutes and shall not differ by more than plus minus 30 seconds form the initial setting time of control test block prepared with the appropriate test cement and distilled water. The final setting time shall not be more than 10 hours.

iii. For RCC works, the Chlorine contents shall be less than 500mg/L and for PCC work, this shall not be more than 2000mg/L.

iv. The pH value of water shall generally be not less than 6 (six) and more than 8 (eight) which can be measured by a pocket size pH meter.



v. A 5% v/v (5ml of NaOH in 100 ml of water) with 0.02N Sodium Hydroxide (NaOH) solution should be sufficient to neutralise the acidity of water to be used for cement concrete works.

1.7 Field Tests for Reinforcement Steel

IS 1786-1985 specifies different field tests for structural steel reinforcement.

i. **Tag Specification**: Check for tag that is marked on the bar in the format "Company Name .. Grade of Steel .. Diameter of bar .. Type of bar" e.g., /// TATA FE 500 / 16mm TMT ///. Grade of steel is mentioned in FE 500 or FE 500 D or FE 415 etc. The type of bar is mentioned as TMT (thermo mechanically treated), TMX (Thermax powered), HYSD (high yielding strength deformed) or SD (Super ductile) for specific requirement of steel.

ii. **Unit Weight:** Non-standard companies manufacture reinforcements with higher weight than the standard by which more steel is required for same work. The unit weight of the bars per meter run shall be checked with the limitation of tolerances as provided in the table 1.7.

Table 1.7

Diameter of bar	Tolerances from standard weight
Up to 10 mm	± 7%
More than 10 mm up to 16 mm	± 5%
Over 16 mm	± 3%

Unit weight per meter of reinforcement bar is computed using the formula $w=d^2/162$, where the diameter (d) of bar in millimeter and the weight (w) in kg/m.

iii. **Bend Test for steel:** When a bar is bend for 180° in the mandrel specified as per the following table 1.7A, there should not be any rupture, crack on the outer face of the bend portion.

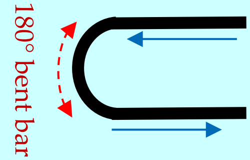
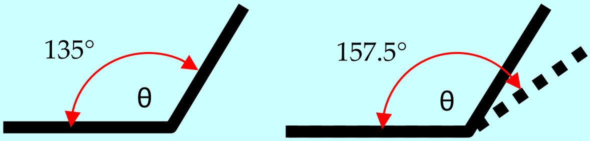


Table 1.7 A (Specified multiplier for mandrel diameter)

Bar Diameter Ø	FE 415	FE415D	FE500	FE500D	FE550	FE550D	FE600
Up to 20 mm	3 Ø	2 Ø	4 Ø	3 Ø	5 Ø	4 Ø	5 Ø
More than 20mm	4 Ø	3 Ø	5 Ø	4 Ø	6 Ø	5 Ø	6 Ø

iv. **Re-Bend Test for steel:** When a steel bar passes the bend test as above, it should be confirmed by a Re-bend test to confirm any rupture or crease. First of all, the reinforcing bar shall be bend to 135° of included angle and boiled in 100°C water for 30 minutes and then the heat is put-off and water is allowed to cool down to normal temperature. Then the bar is straightened to 157.5° included angle to see for any crease or rupture on the outer face of the bend.



Re-Bending Test of Reinforcement bar

Table 1.7 B (Specified multiplier for mandrel diameter)

Bar Diameter Ø	FE 415/ FE500	FE415D/ FE500D	FE500/ FE600	FE500D
Up to 10 mm	5 Ø	4 Ø	7 Ø	6 Ø
More than 10mm	7 Ø	6 Ø	8 Ø	7 Ø

1.8 Cement Concrete Mixes

A mix ratio of concrete is prepared according to the required strength of structure like column, beam, slab, etc. we can also take examples of large structures like a bridge, culvert, dam, etc.

The structure which required to carry more load needs high strength of concrete and a low load needs low strength of concrete to make the structure economical. We have to prepare the required strength of concrete with the help of adjusting the mix ratio of concrete materials.

Here, first of all let's understand what is a mix. Let us take an example. We have to prepare the M20 grade of concrete, then 'M' indicates the mix ratio (ratio of Cement: Sand: Aggregates respectively) of concrete while '20' indicates the strength of concrete in MPa.

As a whole we can say that M20 grade of concrete has its compressive strength of 20 N/mm^2.

Further, the Cement Concrete mixes indicated with special nomenclature in the drawings/ specification are normally in the manner as M15A20 is explained as under:

- First 3 letters M15 shows the compressive strength of 15 N/mm^2 and;
- the last 3 letters indicate the maximum size of coarse aggregates i.e., 20 mm down-graded coarse aggregates to be used in this concrete mix.

1.8.2 Different types of concrete mix ratio

i. Nominal concrete mix/ratio
ii. Designed concrete mix/ratio
iii. Standard Concrete Mix

1.8.3 Nominal Mix ratio: Nominal concrete mix ratio is used for small construction where no actual strength calculation is required. Literary we can say this is the approx value of the ratio of cement, sand, and aggregates for preparing concrete e.g., 1:2:4, 1:3:6 etc. This ratio is measured by volume of each of the ingredients.

1.8.4 Designed Concrete Mix/ratio: Designed concrete ratio is prepared by an expert in the construction. This is an actual and calculated value by structural engineers. There are no guidelines for any grade of concrete. It depends on the structure to be constructed which should bear the load. Engineers initially examine the probable maximum load on the structure and after that the design the concrete mix for cement, sand, and aggregate in the required ratio e.g., M45.5, M74 etc.

Designed Concrete Mix is helpful in places where the materials for concrete with desired specification/quality is not easily or economically available. The designed strength of the concrete is prepared by trial quantity of each of the materials and the strength is verified.

1.8.5 Standard Concrete Mix Design: Standard concrete mix/ratio is based on IS Code 456-2000 concrete mix. It has been separated into different mix ratios of concrete i.e., quantity of cement, sand, and coarse aggregates respectively for different grades of concrete.

The materials (Mix) proportion and the specified compressive strength for each different grades of Standard Concrete Mixes of M5, M7.5, M10, M15, M20, M25 are given as in the Table 1.8.

The full strength of concrete takes in 28 days. To test the concrete, a minimum of three samples of cubes are prepared and tested at each interval of time as per IS 516:1959- Method of test for strength of concrete.

Table 1.8

Grade of Concrete	Mix Ratio (Cement: Sand: Aggregates)	Compressive Strength of Concrete (MPa)
M5	1:5:10	5.0
M7.5	1:4:8	7.5
M10	1:3:6	10.0
M15	1:2:4	15.0
M20	1:1.5:3	20.0
M25	1:1:2	25.0

1.8.6 Observation of Slump in Concrete

Slump in concrete indicates its consistency or workability of the concrete produced for different type of its uses. The more is the slump; more is the workability and this is due to higher water cement ratio. But high-water cement ratio makes the concrete weaker in its strength. However, to maintain its workability for different needs, instead of raising the water-cement ratio; several admixtures like air-entraining agents, water proofing compounds are added to the concrete mix.


Slump Cone

IS-456-2000 specifies values of slump for different uses. A Slump Cone apparatus is used measure this slump. Fresh mixed concrete is put in the slump cone and tamped with the tamping rod to compact. After the cone is removed, the column of concrete within the cone will settle down by its self-weight due to its semi-plastic state. The difference in the height of concrete column after removal of the cone is termed as "Slump". This test is conducted within 10-15 minutes of production of concrete.

The slump prescribed for different uses of concrete as per the following table.

Table 1.8A

Sl. No.	Place condition	Degree of workability	Value of workability.
1.	Concreting of light reinforced sections without vibration or heavily reinforced section with vibrations.	Medium	25mm to 75mm slump for 20 mm aggregate.
2.	Plain cement concrete work	Medium	25mm to 75mm slump for 20 mm aggregate.
3.	Lining with slip form machine for concrete paver finish	Medium	60 to 70 mm slump

1.9 Recommended Frequency of Tests in Construction Stage:

Table 1.9

Norms Adopted for Frequency of Testing of Materials		
A:	**Coarse Aggregate**	
	Screen Analysis	1 in 150 cum
	Specific Gravity	1 in 150 cum
	Soundness	1 in 150 cum
	Abrasion Test	1 in 150 cum
B:	**Fine Aggregate**	
	Screen Analysis	1 in 150 cum
	Unit Weight & Bulkage	1 in 150 cum
	Organic Impurities	1 in 150 cum
	Sp.Gravity & Absorption	1 in 150 cum
C:	**Cement**	
	Fineness	1 in 3 months for each brand of cement.
	Normal Consistency	1 in 3 months for each brand of cement.
	Setting Time	1 in 3 months for each brand of cement.
	Compressive Strength	1 in 3 months for each brand of cement.
D:	**Cement Concrete**	
	Slump Test	1 in each shift
	Compressive Strength	1 in each shift

Additionally, the following Table 1.9A will guide in sampling, basing on the quantity of concrete being used.

Table 1.9A

Quantity of concrete in cum	Number of samples.
1 to 5	1
6 to 15	2
16 to 30	3
31 to 50	4
51 and above.	4 plus one additional sample for every 50 cum or part thereof.

1.10 INTRODUCTION TO SOME TESTING APPARATUS

i. **Cone Penetrometer:** For determining the liquid limit of soils. This is especially useful to obtain reliable and accurate results for those soils which have low plasticity index. The percentage moisture contents determined when cone with half angle of 15-30 minutes under a total sliding weight of 148 gm penetrates 25 mm gives the liquid limit.

ii. **Core Cutter:** This is used for determination of in situ dry density of natural or compacted fine grained soil, free from aggregates. A cylindrical cutter is used to extract a sample of the soil with the help of a dolly and rammer. From the weight, density and the moisture, and dry density of the soil is readily calculated.

iii. **Liquid Limit Device:** Casagrande method in mechanical form is known as Liquid Limit Method. Liquid Limit is the water content at which soil passes from zero strength to an infinitesimal strength, hence the true value of liquid limit cannot be determined. For determination purpose liquid limit is that water content at which a part of soil, cut by a groove of standard dimensions, will flow together for a distance of 1. 25 cm under an impact of 25 blows in a standard liquid limit apparatus. The soil at the water content has some strength which is about 0. 17 N/cm. Sq. (17gms/sq. Cm.) At this water content soil just passes from liquid state to plastic state. The Liquid Limit data of soils is useful to correlate mechanical properties of soil, such as compressibility and lower shear strength.

Cone Penetrometer

Core Cutter

Liquid Limit Device (With Counter)

2.0 SPECIFICATIONS OF BUILDING MATERIALS AND WORKS

2.1 Preparation of Ground for foundation

Before beginning the construction of embankments, the surface area of ground to be occupied shall be cleared of all roots and vegetable matter of any kind stripped to a suitable depth. The stumps shall be pulled or otherwise removed, and the roots grubbed. The stumps and roots removed shall be suitably disposed-off.

Environment safeguards shall be kept in mind while piling the material stocks to keep away the health hazards. The debris shall be disposed-off well-off the worksite, inflammable materials and other dangerous chemicals shall be stored at special demarcated places. Stock of iron & steel reinforcements and the workshop/workplaces for bending or biding of cages of reinforcement shall be properly demarcated/ fenced to entry of unrelated labours/staff and the staff employed here shall wear gumboots and helmets with light reflecting workshop dresses.

The depth to which top soil is removed shall be adequate to remove all perishable material and any soil which may become unstable on saturation or may interfere with development of proper bond between foundation and embankment. It is not necessary to remove all the soil containing fine hair like roots but only heavy mat. The underlain table may offer as a guideline for finding depth of stripping.

Type of vegetable cover in the soil	Depth of stripping.
1. Soil containing light grass cover	5.0 to 7.5 cm.
2. Agricultural Lands	To bottom of ploughed zone 15.0 to 20.0 cm.

2.2 Rollers and Other Compacting Equipment

Depending on the compressibility of various soil, suitability of compacting equipment or method the following table 2.2 provides information on the type of equipment to be used for compaction of different group of soils for embankments, sub-grades etc.

Table 2.2

Major Division	Sub-group	Suitable type of compacting equipment.
1. Coarse Grained Soils	1. Well Grained Gravel, gravel and mixtures of little or no fines.	Smooth wheel roller, Diesel Road rollers of 8 to 10 tonnes capacity, pneumatic tyred roller and vibrating smooth wheel roller.
	2. Well graded gravel sand mixtures with excellent clay binder 3. Uniform gravel with little or no fines. 4. Poorly graded gravel and gravel sand mixtures little or no fines. 5. Gravel with fines, silty gravel, clayey gravel poorly graded gravel sand clay mixtures.	Smooth wheel roller, Diesel Road rollers of 8 to 10 tonnes capacity, pneumatic tyred roller and vibrating smooth wheel roller.
2. Coarse Grained soils, Sand & sandy clays.	1. Well graded sand and Gravely sands, little or no fines. 2. Well graded sand with excellent clay binder. 3. Uniform sand with little or no fines. 4. Sands with fines silty sands, clayey sands, poorly graded sand clay mixtures.	Heavy vibrating plate Frog rammer, pneumatic rammer and power roller.
3. Fine Grained Soils, Soil having low compressibility	1. Silts (in organic) and very fine sands rock flour, silty or clayey fine sands with slight plasticity. 2. Clayey silts (inorganic)	Smooth wheel roller, diesel Road Rollers of 8 to 10 tonnes capacity, power rollers, and pneumatic tyred roller.

4. Soils having medium compressibility	1. Organic silts of low plasticity	Sheep Foot Roller
	2. Silty and sandy clays (Inorganic of medium plasticity.) 3. Clays (inorganic of medium plasticity) 4. Organic clays of medium plasticity.	Frog rammer, pneumatic rammer, padded vibratory roller.
5. Soils having higher compressibility	1. Micaceous or diatomaceous fine sandy and silty soils, elastic silts. 2. Clay (Inorganic) 3. Organic clays of high plasticity.	Smooth wheel roller, diesel Road Rollers of 8 to 10 tonnes capacity and pneumatic tyred roller.

2.3 Mixing of Concrete

Concrete shall be mixed in a mechanical mixer and shall be as dense as possible, plastic enough to consolidate, well and stiff enough to stay in place on the slopes. Mixing shall be continued until there is a uniform mixing of the materials and the concrete is uniform in colour and consistency. The time of mixing shall be as shown in table-1 of IS 457-1957 reproduced below.

Capacity of Mixer	Minimum time for Mixing	
	Natural Aggregates	Manufactured Aggregates.
All mixers	2 minutes	2-1/2 minutes.

Gauge Boxes: Normal weight of 1 bag of cement is 50 kg and 1.226 Cubic foot (cft) or 0.0347 cubic meter (m^3) in volume. So, in volume batching; wooden gauge boxes of size 30 cm x 30 cm x 37.37 cm is used to measure the fine and coarse aggregate.

Calibrated Water Containers: Water-Cement ratio for concrete normally varies in a range 0.4 to 0.6. When W/C ratio for a particular concrete mix is taken 0.56, then the volume of water would be = 50*0.56= 28 kg or 28 liters. Five litre plastic cans calibrated to one litre will be useful in measuring exact quantity.

Air-entraining: Air-entraining from 3% to 4% in concrete by addition of air-entraining agent provides concrete better workability by which the water-cement ratio improves and produces a compact and durable concrete.

2.4 Permissible Limits for Solid impurities in Water

1. Organic solids : Maximum permissible limit 200 mg/l.
2. Inorganic solids : 3000 mg/l.
3. Sulphate (as SO_4) : 400 mg/l.
4. Chlorides (as Cl) : 2000 mg/l for plain concrete work and; 500 mg/l for RCC work.
5. Suspended matter : 2000 mg/l.

The pH value of water shall generally be not less than 6 (six).

If any water to be used in concrete mortar or grout is suspected by the Engineer-in-charge of exceeding the permissible limits for solids, samples of water shall be obtained and tested by the Engineer-in-charge in accordance with IS: 3025-1964.

3.0 ONE HECTARE CAD SYSTEM:

Intensive CAD to one-hectare sub-command is an OIIPCRA initiative wherein a network of channels of water courses is laid to guide the water to reach independently to each one-hectare sub-command. This will save the time and provide irrigation nearly at the same time with very little time-lag to all the tenants, where in the flooding irrigation system; the tail-end plots were irrigated with a delay of more than 7-days compared to head-reach plots.

It has two main purposes:

i. CAD as Irrigation Channel is adopted to carry the irrigation water near to the point of application i.e., nearest to the plant

ii. CAD as Drainage facilitator modified to assist in collection of drainage water from the fields which can be re-utilised down below.

The CAD is purposefully designed to collect the excess irrigation water or precipitations which are normally discarded as drainage from the command to the valley point (Fig-3.0).

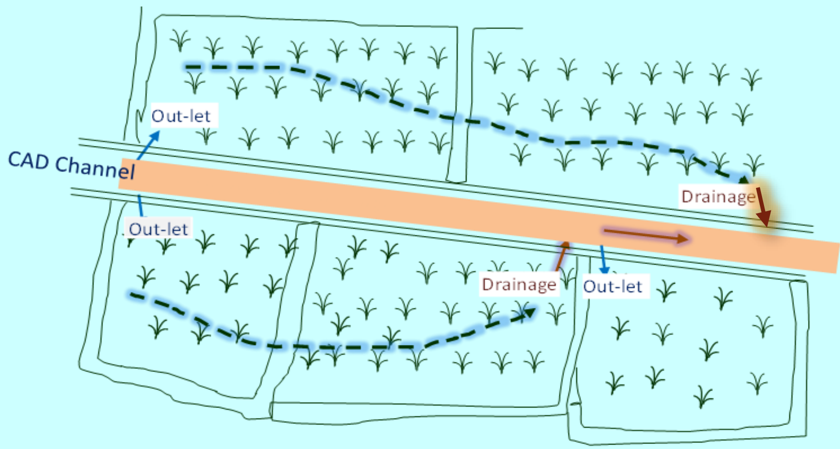


Fig 3.0 CAD Channel – Position of drainage and out-let

3.1 Laying One Hectare CAD System:

The CAD channels are made of Cement concrete with reinforcements to be laid on the common field bunds between plots by replacing the bunds. The channels shall be laid adopting to the natural slope of the fields considering the discharge rate. A table of discharge varying to different bed slopes is provided in Fig-3.1 need to be considered for suitable discharge and terrain slope. Rectangular cuts of 15 cm x 20 cm on the both walls at same chainage are to be provided as outlets to the 1.0 Ha chak (field) with the ground level of start of chak at 10 cm above the channel bed. RCC slabs of 12.5 cm thick may be provided over the channels crossing the regular cart/tractor tracks to allow accessibility of carts/ tractors/ cattle movement.

To facilitate for better drainage of the excess water from the fields, some cuts of size 15 cm x 10 cm (H:V) on the channel wall from Top to FSL are to be made before the point of an out-let in the channel so that the water from the field can outfall into the channel and added to the irrigation water supply.

The drawing of typical CAD section is shown in Fig-3.2 & Fig-3.3 for discharge capacity of 9-26 LPS and 27-60 LPS.

Table 3.1 CAD-WM Channels for OIIPCRA

Rate of Discharge in Rectangular CC Channels for Different Bed Slopes (LPS)									
S =	**1/500**	B E DW I D T H (m)			**S =**	**1/800**	B E DW I D T H (m)		
n =	**0.020**	**0.20**	**0.30**	**0.40**	**n =**	**0.020**	**0.20**	**0.30**	**0.40**
D E P T H (m)	**0.20**	14.71	26.08	38.54	D E P T H (m)	**0.20**	11.63	20.62	30.47
	0.25	19.25	34.61	51.68		**0.25**	15.22	27.36	40.86
	0.30	23.86	43.36	65.28		**0.30**	18.86	34.28	51.61
	0.35	28.52	52.26	79.21		**0.35**	22.55	41.31	62.62
	0.40	33.21	61.26	93.38		**0.40**	26.26	48.43	73.82
S =	**1/600**	B E DW I D T H (m)			**S =**	**1/900**	B E DW I D T H (m)		
n =	**0.020**	**0.20**	**0.30**	**0.40**	**n =**	**0.020**	**0.20**	**0.30**	**0.40**
D E P T H (m)	**0.20**	13.42	23.81	35.18	D E P T H (m)	**0.20**	10.96	19.44	28.73
	0.25	17.57	31.59	47.18		**0.25**	14.35	25.80	38.52
	0.30	21.78	39.58	59.59		**0.30**	17.78	32.32	48.66
	0.35	26.04	47.70	72.31		**0.35**	21.26	38.95	59.04
	0.40	30.32	55.92	85.24		**0.40**	24.76	45.66	69.60
S =	**1/700**	B E DW I D T H (m)			**S =**	**1/1000**	B E DW I D T H (m)		
n =	**0.020**	**0.20**	**0.30**	**0.40**	**n =**	**0.020**	**0.20**	**0.30**	**0.40**
D E P T H (m)	**0.20**	12.43	22.04	32.57	D E P T H (m)	**0.20**	10.40	18.44	27.25
	0.25	16.27	29.25	43.68		**0.25**	13.61	24.47	36.54
	0.30	20.17	36.64	55.17		**0.30**	16.87	30.66	46.16
	0.35	24.10	44.16	66.94		**0.35**	20.17	36.95	56.01
	0.40	28.07	51.78	78.92		**0.40**	23.48	43.32	66.03

CONSIDERATIONS:

Bed Slope = S, shall be considered matching to the average terrain gradient

Rugocity Coefficient **'n' = 0.020**, considered on practical workmanship point of view

Fig 3.2 CAD Channel Section – 9 to 26 LPS Discharge for OIIPCRA

All Dimensions are in mm

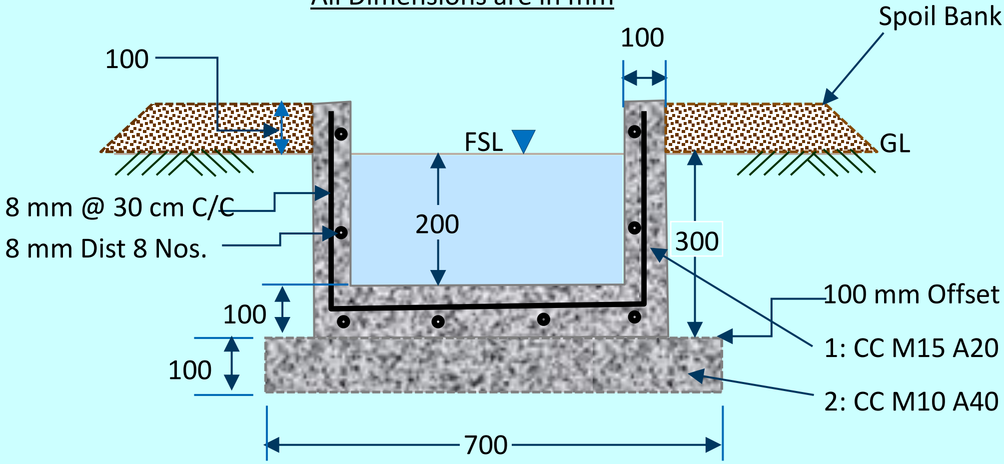
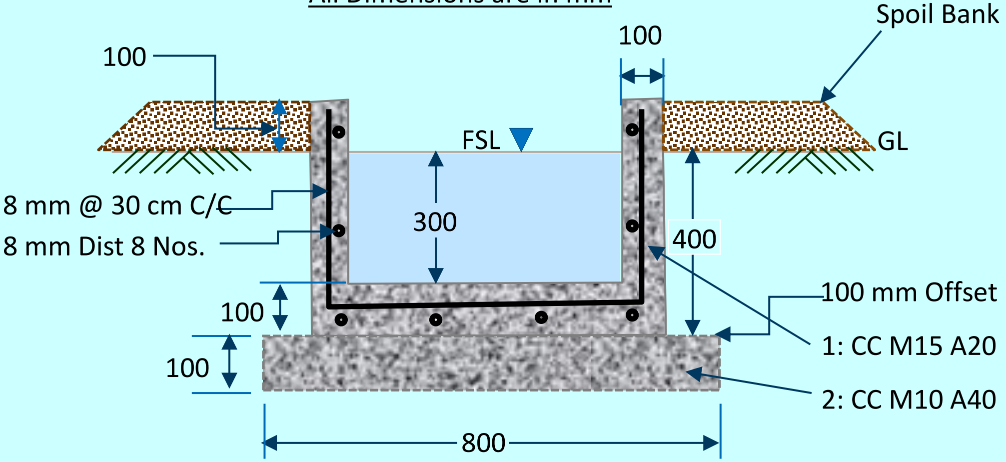


Fig 3.3 CAD Channel Section – 27 to 60 LPS Discharge for OIIPCRA

All Dimensions are in mm



4.0 CONVERSION TO HIGH COEFFICIENT SHARP CRESTED WEIR

When it is observed that the surplus escape width is insufficient to safely discharge the flood computed on 25-year or 50-year projected flood, OIIPCRA recommends increasing the discharge capacity of surplus escape according to current design discharge adopting the following options:

i. to construct an additional spillway (if the present spillway is in very good condition, or

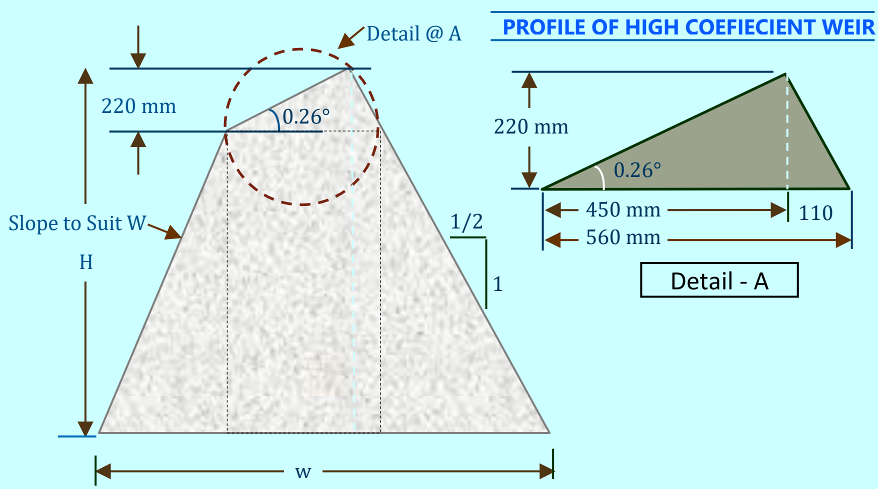
ii. increase the width of spillway if the spillway is deteriorated or one of the abutments is damaged;

iii. If there is no space to construct an additional spillway/increasing the width of spillway and the existing spillway is in very good condition, then the third option is to re-design and convert the broad-crested weir into a high discharge coefficient weir (normally an ogee crested weir) to increase the discharge efficiency.

If the third option is chosen, then the cost involved in conversion to an Ogee crested weir is very high with involvement of increasing the length of downstream apron and also construction of an additional downstream cut-off.

In such situation, OIIPCRA recommends for adoption of a Sharp Crested weir which can be constructed by embedding the existing broad-crested weir and with simple modifications of the crest. The parameters for such changes are depicted in Fig-4.0 which would cost much less than going for an Ogee weir.

HIGH COEFFICIENT SHARP CRESTED WEIR



5.0 PREPARATION OF SUB-GRADE OF CANALS IN SWELLING SOILS

Construction of canals in soils containing organic particles or black cotton soils are avoided. The soil will swell in rainy season which may create breaches in canal, obstruct the steady flow in canal by creating pools of slush in the canal bed. As such, the soil is normally taken-off and the bed and banks are replaced with Cohesive Non-Swelling (CNS) soil. Most moorums of laterite or siliceous sandy clay exhibit CNS characteristics. However, some moorums may be of swelling type. They do not show cracking during summer, nor heaving or sticking during rainy season.

5.1 IS: 9451-1994 recommends the thickness of CNS layers to be placed normal to the canal bed and slopes shall be in accordance as under:

Table 5.1: CNS Thickness in canal carrying discharge less than 2.0 Cumec

Discharge in Canal up to 2.0 Cumec.		Min^{m} Thickness of CNS layer in cm for Swelling pressure of BC Soil	
Cumec	Cusecs	0.50 – 1.50 kg/cm^2	More than 1.50 kg/cm^2
1.4 – 2.0	50 -70	60 cm	75 cm
0.7 – 1.4	25 – 50	50 cm	60 cm
0.3 – 0.7	10 – 25	40 cm	50 cm
0.03 – 0.3	1 – 10	30 cm	40 cm

Table 5.2: CNS Thickness in canal carrying discharge more than 2.0 Cumec.

Swelling pressure of BC Soil in kg/cm^2	Min^{m} Thickness of CNS layer in cm
0.50 – 1.50	75 cm
1.50 – 3.00	85 cm
3.00 – 5.00	100

5.2 Gradation & Index Properties

The CNS soils to be used should be non-swelling with a maximum allowable swelling pressure of 0.1 kg/cm^2 (10 KN/m^2) when tested in accordance with Indian standard, IS: 2720 (Part- 41)-1977. CNS soils are to be broadly conforming to the following range:

GRADATION:	INDEX PROPERTIES
Clay: 15 – 20 %	Liquid Limit: > 30% but less than 50% Plasticity Limit: > 15% but less than 30%
Silt: 30 – 40 %	
Sand: 30 – 40 %	
Gravel: 0 – 10 %	

Note: *Provision for mechanized compaction of CNS soil layers to at least 95% proctor density should be made.*

To prevent contact slides between the CNS material and the expansive soil, the placement of CNS layer is made on the slopes of the embankment after cutting benches or serrations on the sloped face to the required depth as in Fig-5.1.

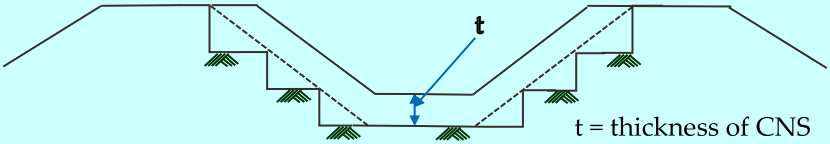


Fig-5.1 Filling CNS in Canal Bed

In small sectioned channels, "fill & cut method" should be adopted after benching for laying CNS in layers of 22.5 cm thick and compacted to at-least 95% proctor density in the full section using small width power drum rollers or standard power rollers. There-after, the compacted section should be scooped out to the proposed design section and the CNS so scooped be re-used in the forward reaches. Provision in the cost estimate should accordingly be made for re-handling of the scooped-out CNS and also some percentage of wastage during re-handling. The Fig-5.2 shows the detail fill & cut procedure.

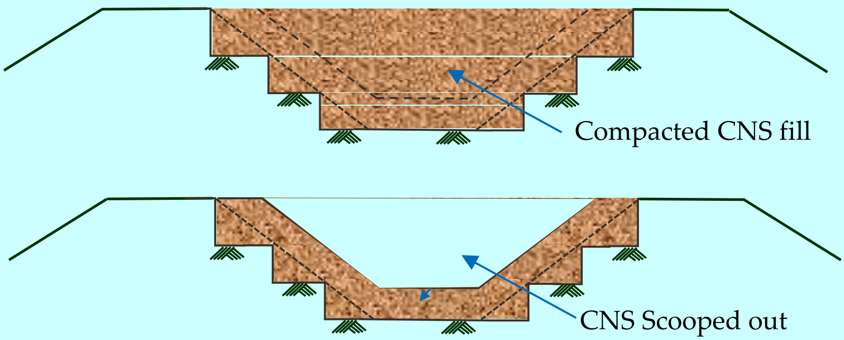


Fig-5.2 Fill & Cut method of CNS in Canal Bed

6.0 CEMENT CONCRETE LINING WORK IN CANALS

Cement Concrete lining of canals is opted when, the seepage losses of water in canals are more or the canal reach is susceptible to regular breaches. Another necessity is to reduce the bed width of canal to carry the same quantity of discharge in comparison to earthen channels in a flat terrain. The advantages are low maintenance due to less silting of the bed. To increase the water use efficiency, OIIPCRA recommends for cement concrete lining of the canals.

Thickness of un-reinforced viz: plain Cement Concrete lining may conform to either the Indian Standard IS: 3873 – 1993 or US Bureau of Reclamation Practice as tabulated below:

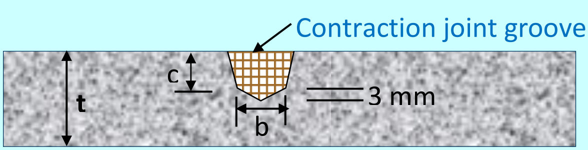
Table 6.0 : THICKNESS OF C.C. LINING as per IS: 3873 – 1993

Discharge Capacity in Cumec (Cusecs)	Depth of Flow in m	Thickness of CC lining in mm
0 – 5 (0 – 175)	0 – 1.0 m	50 – 60 mm
5 – 50 (175 -1750)	1.0 – 2.5 m	60 – 75 mm
50 – 200 (1750 – 7000)	2.5 – 4.5 m	75 – 100 mm

Note: *Taking into consideration the various factors including economy and ease/ practicability of placement & durability consideration it may be appropriate to adopt a lining thickness of **75 mm** for channels of discharging capacity up to 175 cusecs.*

6.1 Execution of CC Walling/Lining:

Cement Concrete Walling or Trough section is recommended up to 50 m from the head regulator from RD 0.00 in the head reach of canals. There after the CC lining shall be adopted providing suitable transitions in-between as per the typical cross sections shown in Fig 6.2 & Fig-6.3 below. M15A20 cement concrete is to be used in Walling/lining of canals. Air entraining agent and well graded aggregates should be used in the mix to get a better workable concrete.



Placement of lining shall be on continuous pattern instead of placing in alternate panels. However, contraction joints should be made by cutting grooves (contraction joint) as shown in the Fig-6.1 when the concrete is still green/plastic. No plastering by cement mortar should be applied to the surface to cover-up the honey-comb patches. Care shall be taken to patch-up these surfaces during concreting by smoothening the concrete with rich cement paste.

Immediately prior to placement of concrete, the subgrade should be thoroughly moistened deploying fine-spray nozzles or the gardeners can. No pressure sprays be used which may erode the sub-grade material.

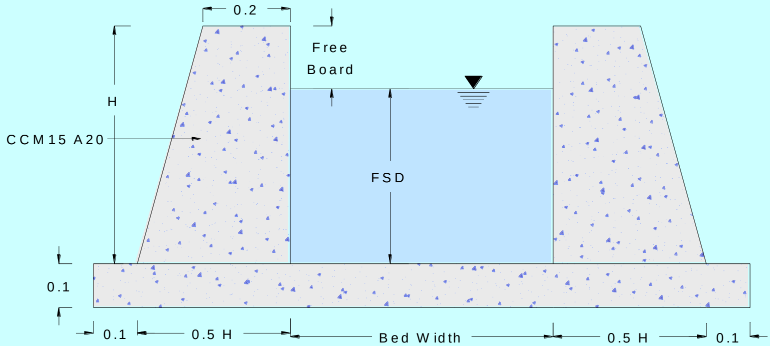
Table 6.1 Contraction Joint Groove dimensions

t	b	c
65-74 mm	9 mm	27 mm
75-100 mm	11 mm	33 mm
More than 100 mm	11 mm	**t**/3 mm

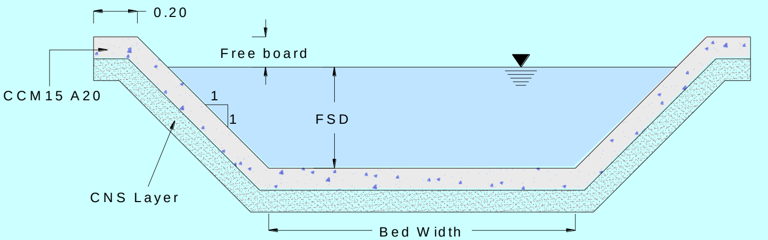
Walling/Trough or Lining sections are shown in Fig-6.2 & 6.3 below for adoption in the projects taken up under OIIPCRA. For canals computed for the bed width below 40 cm, the design sections of canal shall be considered as per the CAD sections provided in Fig-3.2 & Fig-3.3 in the preceding paragraphs.

Fig- 6.2 TYPICAL CEMENT CONCRETE TROUGH SECTION

(Dimensions in m)



TYPICAL CEMENT CONCRETE TROUGH SECTION



TYPICAL CEMENT CONCRETE LINING SECTION

7.0 STANDARD UNITS AND SYMBOLS OF UNITS FOR ADOPTION

7.1 Base Units (MKS)

Name	Symbol[a]	Quantity
second	s	Time
metre	m	Length
Kilogram	kg	Mass
Litre	L	volume

7.2 DERIVED UNITS

Name	Symbol[a]	Quantity
metre per second	m/s	speed, velocity
metre per second squared	m/s^2	acceleration
metre per second cubed	m/s^3	jerk, jolt
radian per second	rad/s	angular velocity
cubic metre per second	m^3/s, Cumec	volumetric flow
square metre	m^2, Sq.m	area
cubic metre	m^3, Cum	volume
kilogram per square metre	kg/m^2	area density, stress
kilogram per cubic metre	kg/m^3	density, mass density
cubic metre per kilogram	m^3/kg	specific volume
square metre per second	m^2/s	kinematic viscosity, thermal diffusivity, diffusion coefficient
kilogram per metre	kg/m	linear mass density
kilogram per second	kg/s	mass flow rate
metre per cubic metre	m/m^3	fuel efficiency
kilogram square metre	$kg \cdot m^2$	moment of inertia
Grams per cubic centimetre	g/cc	Small mass

Name	Symbol[a]	Quantity
Litres per day	Lpd	Mass, discharge
Litres per minute	Lpm	discharge, mass and
Litres per second	Lps	discharge, mass
Square kilometre	Sq.km	Area
Hectare	ha	Area (command)
Kilometre	km	Length
Million Cubic metre	MCM	Volume (large Volume)

7.3 BASE UNITS (SI)

Name	Symbol[a]	Quantity
second	s	Time
milimetre	mm	Length
Newton	N	mass

7.4 DERIVED UNITS (SI)

Name	Symbol[a]	Quantity
newton-metre	N.m	torque, moment of force
newton per second	N/s	yank
newton per metre	N/m	surface tension, stiffness
Newton per square metre	N/m^2	stress
Newton per square milimetre	N/mm^2	stress

7.5 SI PREFIXES APPLICABLE TO ENGINEERING UNITS

Factor	Prefix	Symbol[a]		Factor	Prefix	Symbol[a]
10^9	Giga	G		10^{-1}	Deci	d
10^6	Mega	M		10^{-2}	Centi	c
10^3	Kilo	k		10^{-3}	Milli	m
10^2	Hecto	h		10^{-6}	Micro	µ
10^1	Deka	da		10^{-9}	Nano	n

7.6 CONVERSION FACTORS FROM US CUSTOMARY TO SI UNITS

US customary unit (Symbol[a])	SI unit (Symbol[a])	Multiply by
Acre-foot (acre-ft)	Cubic meters (m^3)	1.23×10^3
Acre (acre)	Hectare (ha)	0.405
Inch (in.)	Milli meter (mm)	25.4
Kilogram force (kgf)	Newton (N)	9.81
Mile (mi)	Kilo meter (km)	1.61
Pound force (lbF)	Newton (N)	4.45
Pound force per square inch (psi)	Kilopascal (kPa)	6.89
Pound mass (lbm)	Kilogram (kg)	0.454
Gallon (gal.)	Litre (L)	3.79
Note: [a] Unit symbols only used when preceded by a numeral.		

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