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CONSTRUCTION OF DIAPHRAGM WALL FOR UNDERGROUND WORKS

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Abstract: Diaphragm Wall is generally reinforced concrete wall constructed under the ground using polymer or bentonite to stabilize the soil or to protect the collapse of soil during excavation. This technique involves excavating a trench that is kept full of fluid of slurry like, (Bentonite or Polymer).

This technique is commonly used in congested areas. Where It can be installed in close proximity to existing structure. Also Used in conjunction with "Top Down" construction technique. Diaphragm wall is widely used in construction of underground Metro station. It is very important structure, as work as a retaining wall also. Indian code for design and construction of diaphragm wall, IS 9556-1980 gives recommendations for construction procedure.

Furthermore this document provides sufficient information on the construction methods including site installations, the personnel to execute the job, major machinery and materials required, inspection and the safety and health matters considered necessary to successfully carry out the construction.

I. INTRODUCTION

Diaphragm Wall is generally reinforced concrete wall constructed under the ground using polymer or bentonite to stabilize the soil or to protect the collapse of soil during excavation. This technique involves excavating a trench that is kept full of fluid of slurry like, (Bentonite or Polymer).

This technique is commonly used in congested areas .Where it can be installed in close proximity to existing structure. Also Used in conjunction with "Top Down" construction technique. Diaphragm wall is widely used in construction of underground Metro station. It is very important structure, as it works as a retaining wall also. Indian code for design and construction of diaphragm wall, IS 9556-1980 gives recommendations for construction procedure of Diaphragm wall.

Diaphragm walls are typically 20m to 50m deep, but may extend to required depth as per the site conditions. There are two type of Diaphragm wall. Temporary and permanent, it can be defined by their uses, when diaphragm wall is constructed to retain only the load of earth pressure for the

construction of permanent structure inside the periphery of the work site .On the other hand when the diaphragm wall is constructed for both the work to carry the load of dependent structure and retaining the earth pressure.

Furthermore this document provides sufficient information on the construction methods including site installations, the personnel to execute the job, major machinery and materials required, inspection and the safety and health matters considered important to successfully carry out the construction.

II. PURPOSE

Diaphragm wall is a type of deep foundation which is design to constructed to bear and distribute the heavy load of the structure, to a safe bearing

This type of work is most suitable where building is situated just near by the construction work site, or likely to get damages during the execution of the work. Now days diaphragm wall is constructed for construction of underground metro station, where the work is carried out by top down construction Technique and soil bearing capacity is low.

III. SCOPE AND APPLICATION OF WORKS

Scope of works includes construction of guide walls, trench excavation using polymer, stop end lowering placing of reinforcement, and concreting of diaphragm wall panels. The scope of this work includes the following activities:

- Setting out survey reference points for excavation of guide wall
- Construction of guide wall
- Excavation of diaphragm wall by grab using polymer slurry
- Check the vertically of trench by using koden machine
- Insert water stopper in stopend groove
- Lowering the stopend by using crane
- Reinforcement cage fabrication
- Insert/ fix couplers as per levels
- Lowering the reinforcement cage (vertically split cage 2 nos for panel) by using crane
- Lowering the tremie pipe for concreting
- Procedure of concreting
- Stop-end extraction by using hydraulic jack and crane
- Excavated muck disposal

IV. FOLLOWING MAJOR EQUIPMENTS ARE REQUIRED WHILE EXECUTING THE CONSTRUCTION WORK.

S No	Description	Qty	Remarks
1	Diaphragm Walls Grab	As per requiremen	
2	Capacity Crawler Crane (100 Ton)	01 no	
3	Service Crane (80 Ton/75 Ton)	01 no	
4	Generator 125 KVA/82.5 KVA	02 nos	Alternatively power supply can be provided
5	Koden Machine	01 no	
6	Polymer Mixing Pump	01 no	
7	Tremie Pipe (250mm Dia) with Hopper	02 Sets	
8	Welding Set	02 nos	
9	Rebar Cutting & Bending machine	02 nos	each
10	Positive displacement Pumps	02 no’s	
11	Polymer Tank (for Fresh Polymer)	03 no’s	
12	Auto Level/Total Station	01 each	
13	Sounding chain & Steel Measuring Tape	01 each	For depth checking
14	Gas Cutting	02 sets	
15	Dumper	02 no’s	For muck removal, as and when required
16	JCB	01 nos	For muck removal, as and when required
17	Stop End	02 sets	
18	Density Checking Kit	02 nos	
19	Electrical vibrator with 40 / 60 mm needle	02 sets	
20	Marsh Cone	02 nos	
21	Measuring Cylinder	01 no	
22	Hydraulic Jacks (200 Ton)	02 nos	For stop end removal

V. MAJOR MATERIALS TO BE USED IN THE CONSTRUCTION OF DIAPHRAGM WALL ARE AS FOLLOWS:

- Water
- Polymer
- Approved Grade of Concrete for guide wall (M20) and diaphragm wall (M40).
- TMT reinforcement bars confirming to IS: 1786-2008
- Cover blocks
- Couplers
- PVC water stop - 230/10mm confirming to IS: 15058

- **Water**

Fresh Water will be used for concreting work and preparing slurry suspension. Water shall be free from solid suspensions and organic matters and shall meet the requirements of IS: 456.

- **Polymer Slurry**

The Poly Mud shall be in accordance with the Manufacturer recommendation.

- **Concrete**

- Concrete shall be supplied by designated batching plant.

- Normal transportation time for Concrete is around 45 to 75 minutes and concrete to be placed within 180 minutes after production. Concrete shall be designed using proper dosage of admixtures so that the required slump (150 to 200 mm for Diaphragm wall) could be available up to 3 hours. This shall take care of any delay occurred during transportation.

- Adequate number of Transit Mixers shall be deployed to ensure the placement of concrete continuously without any interruption. In general concrete shall be produced as per IS: 4926.

- Concrete parameters such as workability and temperature shall be checked at site before unloading the concrete from the transit mixer into the panel. Concrete cubes shall be sampled as per approved ITP/PQP

- The work of checking of workability, temperature, casting of test cubes and their transportation to laboratory and testing shall be performed by QC Department.

- **Reinforcement**

- Reinforcement shall be Fe 500D bars complying to IS 1786 – 2008 and Section S.05 of Outline Construction Specifications of Phase IV.

- TMT shall be as per the approved Drawings for reinforcing steel details. Total lengths of the cage depend on the depth of Diaphragm wall.

- The lifting lugs shall be designed in such a way that they do not cause distortion of cage.

- Lifting of the cage shall be as per approved cage lifting plan.

- G.I Wire shall be used for Binding of Reinforcement.

- **Concrete Cover Blocks**

• The cover blocks to be used for the diaphragm wall cages shall be made by same grade of concrete used in Diaphragm wall construction.

• A minimum cover to main reinforcement shall be maintained as per approved drawings and cover blocks shall be spaced at 1.0 m center to center in staggered manner.

- **Coupler**

Mechanical couplers of threaded type with enlargement at connection by cold forging may be used at appropriate locations Only cold-forged, parallel threaded mechanical coupler system are recommended. All mechanical couplers shall be of Type 2 (or Class H as specified in IS-16172) and should be simple to install and which can be confirmed by quick visual inspection to have been correctly installed and to have achieved the required full strength connection. The couplers shall be of standard parallel thread type. Ends of the reinforcement bars, which are to be joined, shall be enlarged by cold forging/upsetting, threaded in such a way that root thread diameter is not lesser than the parent bar to be joined. The coupler shall be of TYPE - II and qualified/Certified as per IS code 16172:2014,. Couplers installed shall be strictly in accordance with the manufacturer's recommendations. Couplers shall preferably be located away from high stress zones in the various structural elements and shall be staggered. All the couplers shall undergo quality checks on uniformity of threads, dimensional accuracy etc. Each coupler shall be clearly stamped Indicating batch number and diameter. This number shall be traceable to the original cast. The relevant material mill certificate shall be submitted with supply of a particular lot. The certificate shall give salient material properties. The coupler manufacturer shall operate at least an ISO 9000 approved quality assurance programmed or equivalent for the manufacture of couplers.

- **PVC water stop**

Water stopper is used at construction joint of the structure, to prevent the entering water from the joint. It should be confirming to IS: 15058.

VI. CONSTRUCTION OF DIAPHRAGM WALL IS HAVING FOLLOWING STAGES

- Stage 1: General
- Stage 2: Adjacent Properties
- Stage 3: Surveying and setting out
- Stage 4: Guide wall Construction
- Stage 5: Trenching
- Stage 6: Trench Cleaning
- Stage 7: Stop ends fixing
- Stage 8: Reinforcement Cage lowering
- Stage 9: Placing of Concrete
- Stage 10: Withdrawal of Stop ends

- **General**

- Having completed all utility diversion, guide wall trench excavation is executed by using manual excavation for the pre-trench part up to 1.50 meter.

- **Adjacent Properties**

- Allowance shall be made for all ancillary treatment and all work necessary to ensure the stability of road works, adjacent structures and underground constructions and utilities.

- **Surveying and setting out**

- Survey and setting out operations shall be carried out in accordance with approved Guide Wall Layout drawings. Sufficient reference datum and lines shall be available and visible on site for reference.

- Survey and setting out will be done in the following manner:

- Control points will be fixed by Surveyor prior to start of the Guide walls. Guide wall location shall be marked by closing the traverse of three permanent points.

- Temporary pillars for separate centerline and edge line will be made and center points will be marked with the help of total station.

- The Guide walls will be constructed with respect to this center line. Then the reference lines will be marked again on the Guide walls itself for construction of Diaphragm wall.

- All panel nos in accordance with the drawings will be identified on the guide wall.

- Reference levels will be marked on top of the guide wall at each panel location.

- **Guide Wall Construction**

- Guide wall trench excavation will be excavated by manual excavation for the guide wall of 1.5m depth from the existing ground level.

- The Back filled areas and the location of all the Guide wall will be flagged so that overturning of crane/ Machinery would be avoided during the movement.

- Guide wall will be constructed by inverted “L” shaped RCC walls forming a support to the earth and prevents it from collapse when the boring of diaphragm wall. Guide wall will be constructed prior to the excavation of the diaphragm wall.

➢ The purpose of guide wall:

- To provide a permanent alignment for the grab.

- To provide edge protection to the diaphragm wall and to prevent the collapsing of soil during the excavation/grabbing.

- To act as a platform to hang the reinforcement cage and maintain the coupler levels.

- The following steps will be involved in construction of guide wall:

- Before excavation for guide wall a valid “Permit to Work” must be issued.

- The trench will be excavated as per set out and indicated alignment.
- Manual excavation Excavator for guide wall trench up to 1.5mdepth from the existing ground level.
- Fixing of reinforcement will be done as per the approved drawing.
- The minimum cover to reinforcement shall be as per the approved drawings. Cover blocks will be used to maintain the cover at both faces of reinforcement.
- Formwork will be fixed after proper cleaning the inner face and applying proper de-shuttering oil.
- The clear horizontal distance of guide wall i.e., diaphragm wall width plus 50mm will be maintained.
- Joints between shutters will be sealed to avoid leakage of cement slurry.
- Placing of M20 grade of concrete with proper compaction.
- De-shuttering will be done after concrete gets set and the area will be backfilled for safety purpose. Battens will be provided for maintaining clear distance between both ends.
- After concrete gets hardened curing shall be done.
- The trench face of the guide wall on the side of the trench nearest to the subsequent main excavation shall be vertical to within 1:200.
- Variations from a straight line or a specified profile shall not exceed 25mm in 3m.
- In soft ground shoring to be done in guide wall to prevent deformation of guide wall under pressure of heavy crane/ rig.
- **Construction of Diaphragm Wall Panel Sequence**
- Diaphragm wall shall be constructed as per approved GFC drawings. Based on the site condition, either of the two methods described below shall be implemented.
- **Successive Panel Method**
- In this method a panel shall be cast in continuation of previously completed panel.
- **Alternate Panel Method**
- In this method primary panels shall be cast first leaving suitable gaps in between secondary panels shall then be cast in these gaps. Two stop end plates shall be used at the ends of the primary panels to support concrete and to form suitable joints with the secondary panels.
- The structural diaphragm wall construction sequence is first starter panel and followed by follower panel.
- After completion of panel excavation, two stop ends shall be placed with water stop for trench extremities for starter panel. Verticality of the stop end shall be ensured by checking it through the plumb bob and sprit level.
- When everything is in order including the polymer mud in the panel trench, the steel reinforcement cage may be installed.

- Before concerting takes place, sandbags could be placed in such manner for adequate support to the stop-end to maintain verticality and facilitate their extraction.
- Once the steel is in place and the polymer characteristics checked, concrete placement shall take place.

Essentially, the phases involved are:

- Excavation
- Final depth sounding
- Checking parameters of each panel.
- Installation of stop ends with PVC water stop
- Installation of steel reinforcement cage
- Introduction of tremie pipe.
- Placing of concrete
- Dimension of the Panel (Panel size shall be as per approved drawings).
- **Excavation for Diaphragm Wall**

- Diaphragm wall shall be constructed using primary, secondary, and closing panel method.
- **Primary Panel**

Primary panels are the panels constructed along the alignment of the wall in the first series leaving suitable gaps for intermediate / secondary panels. Primary panels shall be casted with Stop-ends at both ends for interlocking with the secondary panels.

- **Secondary Panel**

Secondary panels are the panels constructed along the alignment of the wall in the second series and interlocked with the other panels constructed in first series (primary panels/secondary panels). The size of the panels shall be varying at the corners to suit the alignment requirement. Secondary panels shall be casted with one side stop end and other side constructed panels.

- **Closing Panel**

Closing panels are the panels constructed along the alignment of the wall between other constructed panels. The size of the panels shall be varying at the corners to suit the alignment requirement.

- **Casting Sequence of Panels.**

- The diaphragm wall will be located between the guide walls. The guide wall will be marked with the panel reference number and center line of stop-end position. The guide wall will have been strutted and backfilled prior to excavation to prevent movement or settlement.

- The trenching will be carried out by hydraulic rig with grab. The hydraulic rig grab operates through hydraulic power of the rig. The swing, leveling, hoisting, closing, and lowering of grab is controlled by the rig.

- Once the grab is set up over the designated location (checked visually against color marker pegs and the number on top of guide wall), the operator shall lower the grab onto the ground and commence trenching.
- As trenching proceeds, polymer drilling fluid shall be used to stabilize the excavated trench.
- Excavation by grabbing will be done in presence of the polymer solution. The density of fresh polymer solution for circulation will be kept more than the normal density to ensure the stability of the trench. It must be ensured that the polymer slurry level shall be maintained at 150mm above the bottom level of the guide wall
- Prior to commencing actual excavation, the grab rig will be set up vertically, on one side of the diaphragm wall axis.
- Verticality of grab attached to the guide shall be checked by using the computerized sophisticated electronic verticality meter attached to the device and will be used and constantly monitored to immediately detect any tendency of the excavation to deviate. If any deviation is observed during grabbing, operator shall readjust the grab immediately, if any deviation is observed in the casted panel after excavation, it shall be rectified as per approved quality assurance plan.
- Whether the panel is a starter or follower one, there is no difference in excavation method. The grab is lowered polymer in an open position, closed and retrieved full of spoil.
- The standard panel will be excavated in three main “bites”.
- The first “bite” will be excavated to the design toe level. The second “bite” will be a repeat of the first and finally the third “bite” will be the center portion.
- Grabbing will start in presence of polymer solution from one bites of the panel and will excavate up-to the founding level i.e., up-to the required depth of excavation as per the cross-section details of approved drawings.
- The rig is then shifted to the second bite of the panel and excavates up-to the founding level. Then the rig is shifted to the middle bite of the panel and excavates up-to the required depth. This gives us a full-length excavated trench of the panel. The panel bottom is then cleaned by final grabbing.
- When the grab reaches guide wall level upon exit, a momentary suspension is recommended to allow the excess mud to drain from the spoil through the drainage holes of the grab. The operator then rotates the rig and discharges the spoil either into skips or onto the ground.
- As excavation proceeds, polymer is pumped into the excavation to ensure it is kept full and within the level of polymer slurry must always be maintained at prescribed level. During the excavation, and upon reaching final depth, the panel depth is verified using a sounding chain and measuring tape. Logging of slurry will be carried out during the excavation to check the slurry losses.
- Verticality shall be checked for every diaphragm wall panel by Koden. During the excavation of each panel, initial verticality of the panel shall be checked two times (After 50% excavation and 100% excavation of the diaphragm wall panel for the initial five panels subsequently it shall be checked after100% excavation

for each panel).

- The plane of the diaphragm wall face to be exposed shall be vertical to within the tolerance as mentioned in the general notes /OCS.
- Excavated muck mixed with polymer slurry will be kept aside, and the same will be disposed of in the dumping yard at the appropriately designated dumping yard.
- **Exceptional collapse of the Panel**

- Should any exceptional collapse affecting the safety of the neighboring areas occur, the panel will be immediately backfilled with cement slurry of grade M3 and the excavation will resume after an appropriate time.

- If in case of large time expected or machinery repairing more than 24 hours the panel will be filled by sand to prevent any damage to the close buildings

- **Mud cleaning and disposal**

Mud cleaning and disposal will be in accordance with contract / technical specifications.

- Cleaning of diaphragm walls by sedimentation of the suspended particles to the bottom of the excavation, ensuring the stability.

- Spoil slurry mixed with the excavated soil will be kept aside / loaded on trucks with JCB then safely transported and disposed at Mundka dumping yard for polymer mud mix.

- There will be a provision of cleaning arrangement to ensure proper cleaning of the entire sub-frame of dumpers before it fly on public road.

- During the transportation special care like green nets shall be covered to avoid the spillage of mud from the trucks.

- **Check for Tolerances & Verticality**

Construction shall be carried out in accordance with the following normal tolerances, unless otherwise defined by the Contractor's drawings or procedures.

- For straight or other specified profile panels, the minimum clear distance between the faces of the guide walls shall be the specified diaphragm wall thickness plus 25mm, and the maximum distance shall be the specified diaphragm wall thickness plus 50mm. The guide walls shall be propped as necessary, to maintain these tolerances, and the inner guide wall shall be constructed to the line as shown on the drawings. Finished faces of guide walls towards the trench shall be vertical and shall have no ridges or abrupt changes. Variations from straight line or specified profile shall not exceed 25 mm in 3m.

- The trench face of the guide wall on the side of the trench nearest to the subsequent main excavation shall be vertical to within 1:200. The top edge of this wall face shall not vary from a straight line or the specified profile by more than +15mm in 3m and shall be without ridges or abrupt irregularities.

- The plane of the diaphragm wall face to be exposed shall be vertical to within the tolerance of 1:200, relative to a vertical line projected from the base of the guide wall. In addition to this tolerance, 75 mm shall be allowed for protuberances resulting from irregularities in the ground excavated beyond the general face of the wall.

- The ends of the panels shall be vertical to within the tolerance of 1:200.

- Where recesses are to be formed by inserts in the wall, they shall be positioned within a vertical tolerance of ±75mm, a horizontal tolerance measured along the face of the wall of ±75mm, and a horizontal tolerance at right angles to the face of the wall as constructed of ±75mm.

- Tolerances for Reinforcement cage shall be as follows; Clause 13.5 of OCS of phase IV.

- **In positioning**

- Longitudinal tolerance of Cage head at the top of the guide wall and measured along trench1; - +/- 75mm
- Vertical tolerance of cage head in relation to the top of the guide wall: +/- 5mm.
- Lateral tolerance of reinforcement position in the direction across the width of wall shall be: +/- 50mm.
- 9.9.2 In positioning of couplers and starter bars
- Longitudinal tolerance +/- 75mm
- Vertical tolerance +/- 50mm
- Lateral tolerance +/- 50mm
- A minimum cover to main reinforcement of 75 mm shall be maintained. Minimum clear distance between reinforcement bars shall be100 mm.
- Notwithstanding the requirements of this Subsection the tolerances may be aggregated only to the extent that they do not exceed 250mm.
- In case of laps being used, detailing as per approved drawings shall be followed.
- Alternatively, Couplers may be used to avoid laps as per the approved drawing.
- The placement of coupler shall be as per the approved drawing.
- All D wall cage shall be fabricated as per approved drawing.
- **Method of Monitoring and Protection**

- Method of monitoring protection shall be in accordance with the provisions of the specifications. Before starting the excavation, the survey shall be completed.

- During excavation monitoring shall be required to check the settlement and displacement of ground according to Instrumentation plan and approved method statement. According to Monitoring shall be done to check the movements of adjacent structures, services and underground construction.

- Observations shall be made at regular intervals. Measurements shall commence one week before the starting of the excavation and shall be continued till completion of the work.

- All instrumentation and monitoring shall proceed in accordance with the Method Statement for instrumentation and monitoring, which shall be prepared and submitted separately.
- **Mixing, Transportation and Placing of Polymer Slurry**
- Polymer should be test as per SOP.
- The diaphragm wall excavation will be done by soil support polymer slurry to prevent collapsing / caving in soil inside the panel.
- Polymer shall be prior to usage and polymer shall be stored in a designated area, under shed / Cover.
- Suspension will be prepared accordingly to the manufacturer specification and any other indications given by Geo technical consultants on site (depending on site geological conditions).
- Polymer shall be mixed in a purpose designed colloidal action batch mix- mixer. The polymer shall be mixed with water in a concentration as per recommendations of the manufacture and depending upon the site conditions and slurry properties as per relevant standards.
- After inspecting for the desired properties as per ITP of the freshly mixed polymer slurry, the same shall be transferred from storage to the excavation area by suitable capacity pump and pipeline.
- To assure that the polymer slurry is in accordance with Manufacture recommendation, the quality of the slurry used for the excavation will be verified during preparation and excavation, prior to concreting (before steel cage lowering) following test required.
  - Density
  - Marsh viscosity
  - Sand content
  - pH
- The site shall be equipped with the following instruments:
  - Fluid sampler
  - Marsh funnel
  - Stopwatch
  - Graduated cylinders or Cup
  - Mud balance
  - Sand-content kit
  - pH papers
- If a panel were to remain open for 24 hours, each shift the above-mentioned tests will be performed (top, middle and bottom excavation level) and the panel trench topped up with fresh mud: if necessary, the slurry will be replaced or regenerated. Quality of slurry will be verified twice per panel.

Parameter	Fresh Slurry	Reused Slurry	Prior to the concrete pour	Test Methods
Viscosity(seconds/litre)	34-143	>55	>50	Marsh Funnel
Density (g/cc)	1.025 (max)	1.00-1.06	<=1.06	Density balance
Sand Content (%)	1.00 (max)	-	<=3.00%	API 13B-1 Section 5 of OCS
pH	8-11	11-12	7-12	pH paper or meter

Table-1: Slurry specifications of Polymer

- **Installation of Stopend and Water stop**

• Stop end to be designed to take tensile stress during pulling out specially in deep D walls in stuck condition.

• After completion of grabbing up to a required depth, the trench will be cleaned and the stop-end along with the water stoppers will be installed.

• The stopend will be cleaned, greased and the water stopper shall be fixed in the stop end groove and to be ensured that while lifting the stop end the water stoppers do not slip from the groove. Before lowering the cage, the stopend attached with the water stoppers are lowered in the trench, which mark the boundary of panel so that fresh concrete does not come in direct contact with the soil in the next panel. The stop ends and water stopper details are as per attachment. In case of primary panel 2 nos. of stopend must be introduced at both sides, for follower panels 1 no. of stop end shall be fixed whereas in case of closing panel no stopend is required to be introduced.

• The shape of the stop-end shall be such that it shall provide sufficient key at joint to secure a watertight connection between the panels. The stop-end shall be clean and have a smooth surface.

• Water stopper of approved quality as per drawing & specification shall be fitted into the groove of Stop-end to make the panel joints watertight.

• After ensuring the fitting of water stopper, stop-end shall be lifted by crane &slowly lowered & positioned into the trench. It shall be positioned by fixing a removable temporary clamp at top of guide wall.

• The stop end will be lowered straight and shall be kept vertical with the help of concrete block. After fixing the stop end, the panel dimensions will be checked and ensured that it should be within tolerance limits. Verticality will be checked and monitored with the help of plumb-bob and sprit level keeping parallel and perpendicularly to the stopend. The tolerance of stopend shall be in 1:80 ratios.

- **Fabrication & Lowering of Reinforcement cage**

Before starting the erection of cage, the following precautionary will be taken care:

- Barricading will be provided for guide wall.
- Proper lifting and erection will be done carefully lowered vertically downward under supervision avoiding edge breakings to guide wall.
- Cage shall be fabricated with a cage of length 6m approximately.
- The lifting and placing cage shall be done with the help of 2 Nos of cranes by tandem lifting, with the support of cage Lifter. The cage lifter will be fixed directly to the lifting hook of the cage with D-shackles and slings of the Primary Crane 150T lifting capacity cranes. The bottom end of the cage shall be fixed to the second crane 80T with two slings will be ensured.
- The lifting beam will be designed according to the calculation provided by design team will be ensured for fabrications.
- Earthing provision shall be provided to reinforcement cage to protect worker from electrocution while fabrication.
- The cages will be properly tagged as below:
  - Panel No.
  - Status of Inspection
  - Approved for use
- Reinforcement shall be fabricated as per Bar Bending Schedule and shall be stacked over a firm ground such that the rebars are not soiled.
- Fabrication of reinforcement cage may be done at a location nearer to the Diaphragm wall activity area, on a firm ground and working platform for cage fabrication.
- It should be ensured that there should not be any reinforcement hindering the tremie location in cage and the same shall be shifted/ bend if there is any hindrance in order to ensure smooth concreting of D-wall panels
- As per the approved drawing, inclinometer pipe of 125mm Dia shall be fixed in the panel reinforcement cage.
- Reinforcement cage shall be tied with GI binding wire. Once the cage is inspected and rectification attended to, the cage shall be tack welded. Cage shall be fully welded at number of places to make sure that the cage is rigid enough to withstand forces during cage lowering into trench.

- Reinforcement shall be adequately fixed with spacers / chairs between the rows of rebars at certain distances, to avoid displacement and to maintain the minimum specified cover.

- Thereafter, reinforcement cage shall be shifted nearer to the panel location by using crane.

- In either case as mentioned above, in the pre-fabricated cage, the couplers are fixed on to the Threaded bars as indicated in the approved drawing and are protected against displacement during Lowering of Cage and against concrete concreting the couplers, as per the detailing made in the approved drawings.

- Length of top lifting hook shall be calculated based on the Guide Wall Top level & Diaphragm Wall Cut Off Level and it shall be properly welded to main reinforcement to withstand the total load of cage during lowering &locating operation. These Lifting hooks shall be placed over resting beam placed on the guide wall top to maintain the reinforcement top as per drawing.

- Provision / sufficient opening shall be kept while fabricating the cage for lowering of tremie pipes for tremie concreting.

- The reinforcement bars used for fabrication of cage shall be clean and free from loose mill scales, dust, rust, oil, grease & other coatings which may reduce the bond with concrete. Front & rear face of the cage shall be properly marked to identify the faces during lowering of cage.

- Lifting points, hooks shall be properly designed & shall be provided into the cage without disturbing the reinforcement of diaphragm wall. These shall be capable of sustaining forces generated during lifting lowering & lowering the cage into the panel.

- **Cage Lifting Plan**

- **Purpose**

In order to provide a safe system of work and to ensure compliance with this, site lifting plan has been developed and is to be implemented by Site team and Crane Operators/associated workmen with fundamental safe working procedures to be followed during reinforcement cage lifting operations.

- **The lift plan provides guidance on:**

- Responsibilities and competence of personnel involved In lifting operations; Execution of crane operations;

- General instructions for Crane Operators;

- General instructions for Banks men and Load Handlers.

- The objective of this document is to clearly understand the job and procedures of execution along with safety precautions, which are necessary to avoid any kind of injuries/accidents to personnel or any damage to any equipment's or property and maintaining the quality of works.

- **Scope**

This procedure covers crane lifting operations undertaken by personnel employed by either directly or through sub-contractors at work place during construction of diaphragm wall.

The scope of work involves the following works:

- Option 1 (Lifting the Reinforcement Cage with One Crane) Lifting of Cage using Crane and Lowering in to the trench.
- Bottom Cage will be kept in suspension with channel or other suitable supports on the Guide wall to overlap the top cage,
- Lifting of Top Cage using Crane and positioning it on top of bottom cage .
- Lapping of Bars using Welding of Bars/Using "U" Clamps Lowering of Cage in the Trench

VII. CONCRETE

Concrete shall comply with the general requirements of technical specifications and IS 456:2000.

- **Level of work**

- Diaphragm walls shall be concreted to the levels shown on the approved drawing.
- The effective trimmed final wall levels shall normally be taken as 250 mm below top of guide wall when concrete is cast-up to top of trench. If water table is high and if required cut off is low and water table is also at depth, concreting can be stopped at lower level subject to approval of clients representative.
- Concreting of diaphragm wall shall be done continuously without interruption to ensure no mixing of polymer with concrete.
- Before start of concrete works a steel, grill will be provided over the guide wall to prevent the falling of persons in the excavated trench.
- Before concreting the following parameters, value shall be followed.

Parameter	Value
Slump	150-200mm
Temperature	>5°C &<32°C
Frequency of cube sampling	As per the approved ITP

- With the steel reinforcement in place the tremie pipe of internal diameter of 250mm along with the hopper attachment is lowered at the center of the point to have uniform fill of compacting concrete in panels. The tremie pipe is set at 300mm from the bottom of the excavation and suspended by a self-locking working platform. All joints in the tremie pipe must be made watertight and inspected at every make-up. Any pinched O-rings or damaged threads must be discarded and replaced.

- This will be done by skilled supervision on daily basis to ensure the correct procedures to carry out all measurements and recording. In fact, upon completion of assembly, the tremie pipe will be lowered to contact the bottom of the panel to check that the length is sufficient and cross-check the recorded length.
- At the start of concrete placement, a plug is placed at the bottom of the funnel, protected by a shovel until the hopper is full of concrete. The shovel is then removed and the concrete gushes down the tremie, thus keeping the concrete away from mixing with the polymer slurry.
- Diaphragm walls shall be concreted to the levels as per the approved drawings.
- During concreting arrangements shall be made for transferring back the polymer in slurry tank ensuring that the polymer in panel shall not fall below the Guide wall bottom level.
- During the concreting tremie pipe will be kept always immersed below the surface of the fresh concrete. Except at the beginning, the immersion depth inside the concrete will be not less than 2m. The concrete level will be measured at regular intervals after evacuating each transit mixer by measuring tape with sounding chain so that the actual volume of concrete placed can be compared with theoretical panel volume. The results of these observations will be used to produce a concrete volume curve for each panel.
- Concrete will be poured continuously till the panel is filed up above the theoretical cut-off level.
- After completion of concreting and final setting of the concrete, the stop ends are fully removed out of the panel with the help of extracting jack system.
- As precautionary measures steps against choking of Tremie pipe, extra tremie pile will be kept ready while concreting to immediately replace on choking condition. Proper slump as per mix design shall be maintained. Regular vibration of tremie to followed.
- Test cubes shall be made and tested in accordance with the specification. Test cubes shall be taken for each panel constructed. Cubes shall be marked with the wall panel numbers and shall be sub-marked within each panel set to indicate a location within the panel.
- Inserts shall be formed at the locations shown in the Contractor's drawings and in accordance with his method statements and procedures.
- Extraction of “Stop-end"- Extraction of Stop end shall be carried out using the following method
- Jacking arrangement - Both the Stop-ends, provided on two ends of the cages, shall be lifted by means of extraction frames place over Guide walls.
- Each "extraction frame" made from Structural steel is placed around the Stop-end over Guide wall and Tightened by Bolts such that the Stop-end is Gripped by the extraction frame like Friction clamp.
- 200 T Hydraulic Jacks (2 no's one on each side of the Extraction frame) shall be introduced over Guide wall at the center of Extraction frame, with steel plate/ply board packing below and above Jacks (over Guide wall and below Extraction frame).
- Once the concrete starts to set (3~5 hrs.), Jacks shall push the extraction frame up, such that Stop-end, gripped by the extraction frame, moves up.

- The end of Stop-end is held over by a crane of enough capacity to take care of Stop-end from falling side wise due to its length. After one (1) complete stroke of jack—approx.

50 cm is over, and when Crane holds the Extracted portion of Stop-end, the Extraction frame is De-bolted with support of auxiliary hook of crane and brought down, re-clamped with Stop-end and Operation of Lifting up the Stop end is continued.

- Once it is observed that after several such strokes, the Stop-end is free from Water stopper, The Stop end is lifted by the Crane