Inadequate space in urban settings has set forth a challenging trend to go deeper into the ground and to increase the space required for providing public amenities, parking, housing utilities, industrial mass storage, etc. The space constraints necessitate the deep excavations to have earth retaining systems. One of the important earth support system is Diaphragm wall. This paper is an attempt to increase the awareness on latest Diaphragm wall systems, equipment and technologies available in India.

Underground space creation has gained importance in the Indian cities to help release scarce land resulting from rapid growth in population. Underground space structures are thus becoming common for deep basements of residential buildings and shopping malls; underground Metro Rail Transit Systems for both roads and railways. Further, underground power houses, water curtains below dams are some of the underground structures in the heavy infrastructure facilities.

Open excavations for construction of such underground structures quite often becomes impossible due to closely spaced structures in the vicinity of excavation, very high water table conditions, difficult soil conditions, existing underground utilities in close proximity, stringent restrictions to lateral ground movements, etc. Excavation support systems under such conditions become necessary. However, provision of proper excavation support system has always suffered from commercial considerations rather than from a careful techno-commercial consideration. A key factor to careful techno-commercial consideration can be through awareness about the availability and proximity to various methods, technologies and equipment for construction of excavation support systems.

Common Types of Earth Support Systems
Depending on excavation depth, ground conditions, ground water level, allowable vertical and horizontal displacements of adjacent ground, water tightness requirements of support system, availability of construction know-how, cost factors, subsequent construction methodology, working space limitations, etc., the following types of deep support systems are commonly used.

- Diaphragm walls
- Secant / contiguous Pile walls
- Sheet pile walls
- Soldier pile with wooden lagging walls

Piled walls (b. to d. above) use rotary piling equipment which are common in India now a days. However, the Diaphragm wall and related equipment are yet to gain popularity and understanding amongst the stack holders. The following sections, construction of diaphragm walls and the related equipment are discussed.

Diaphragm Walls
Diaphragm wall is an underground wall constructed from the ground level to support excavation sides from lateral earth pressure and water pressure, and to provide water tightness to the underground structure. Diaphragm walls can be temporary if they only support the sides until construction below ground level is completed. They can also be permanent if they form part of the main wall of the underground structure.

Diaphragm walls find the following applications: earth and water retention walls for deep excavations, basements, and tunnels; High capacity vertical foundation elements; seepage control walls under dams, etc. These are also used as a permanent basement walls for facilitating Top-down construction method.

Typical wall thickness varies between 0.6 to 1.5m. The wall is constructed panel by panel in full depth. Panel width varies from 2.5m to about 6.5m or even more depending on various conditions. Short widths of 2.5m are selected in less stable soils, under very high surcharge or for very deep
walls. Different panel shapes other than the conventional straight section like T, L are possible to form and used for special purposes. Traditionally, panel excavation is carried out using cable supported Grab. Hydraulic grabs with Kelley arrangement have recently been introduced in India on large Infrastructure projects. More recently developed hydraulic cutter type machines have also entered few projects in India. Apart from the Diaphragm wall excavation equipment, other equipment involved are cranes for reinforcement lowering, pumps, tanks, de-sanding equipment, air lifts, mixers etc.

Steps involved in the construction of diaphragm wall can be broadly listed as follows:

- Guide wall construction along alignment
- Trenching by crane operated Grab/ hydraulic grab or trench cutter
- Bentonite flushing
- Lowering reinforcement cage
- Concreting using tremie

The sequence of diaphragm wall panel construction is schematically illustrated as below.

It must be remembered that Diaphragm walls are constructed as a series of alternating primary and secondary panels. Alternate primary panels are constructed first which are restrained on either side by stop-end pipes. Before the intermediate secondary panel excavation is taken up, the pipes are removed and the panel is cast against two primary panels on either side to maintain continuity. Water stoppers are sometimes used in the construction joints between adjacent panels to prevent seepage of ground water.

Equipment for Diaphragm Walls

Diaphragm wall construction involves heavy construction equipment. These equipment can be grouped based on three major activities viz. trenching, reinforcement lowering, concreting.

Trenching activity involves a network of equipment consisting the trench excavation equipment, desander or decanter and slurry handling pumps. A typical network for trench excavation is illustrated in the sketch below.
mechanical grabs excavate the panel trench through all types of soils with fairly good verticality control.

Hydraulic grabs (Fig below) are generally rope suspended or Kelly guided with sufficient weight and length and mounted on a suitable hydraulic crane or mechanical crane with power pack. The closing forces of 180 MT is quite common. The above features help these mechanical grabs excavate the panel trench through all types of soils and hard formations with good verticality control and higher productivity.

Trench cutter (Fig above) which is otherwise called as Hydromill or Hydrofraise is a latest development. The features in this equipment enables trenching through all types of soils and rocks with greater verticality control and speed. The cuttings of the trench excavation is carried by trenching slurry and removed at a desander. The desanded slurry is circulated back in the trench. Verticality of the excavation can be controlled by using hydraulic flaps available in the cutter frame. This way, the trenching is continuous, fast, straight and clean.

Prefabricated diaphragm wall reinforcement cage is inserted, once the trenching is completed. This requires one or two cranes for lifting and lowering activities as shown in picture below. Reinforcement cages of lengths varying from 12m up to even 25m with weights ranging between 10T to 25T can be lifted and lowered in single piece. However, depending on the availability of space and crane capacity, reinforcement cages can be lifted and lowered in pieces and lapped during lowering.

Diaphragm wall concreting is done by tremmie method and hence the concrete must have adequate workability to ensure smooth flow from bottom of panel to top of panel, completely replacing the slurry without mixing. Typically, each diaphragm wall panel would require about 50 to 200 cum of concrete in a span of 4 hours. Hence, production of diaphragm wall concrete is a careful decision to be made considering the availability of Ready Mix Concrete (RMC) plants in the closer vicinity and the logistics. A typical concrete pouring operation is shown in the picture below.

Summary & Conclusions:

In the foregoing sections, diaphragm wall as earth retaining system of deep excavations was outlined with brief method description and major equipment required for the same. While many of the minute details of diaphragm wall construction are not discussed here, the author would like to bring the attention of the readers the following.

Diaphragm wall structurally resist and protect the life and facilities of underground structures from the soil and water pressures and the leakages. In achieving this, concrete and the method of concreting assumes greatest importance and throws many challenges such as logistics through metros to bring concrete to the tune of about 200cum within 5 hours and without compromising quality. Hence, the author would like to appeal the readers to research better methods of in situ concrete production and placing for Diaphragm wall construction.