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Research Paper

METER PANEL CONSTRUCTION, AN INNOVATIVE SOLUTION FOR BASEMENTS, SUBWAYS AND RIVER TRAINING WORKS

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There is growing need of basements, subways and other underground excavations in congested cities. Considering proximity of other structures and traffic problems open excavation may not be always feasible. Panels of small width, forming a wall are constructed along retention periphery, adequately designed as cantilever sheet piles and anchored in substratum to achieve stability against various forces may be adopted here. The particular problem is studied; equations developed for stability considering passive pressure and balancing couple by trial and error method, the results are verified with analytical model (FEM). Results are presented here.

Keywords: Meter panel, sheet pile, Alternate method, Segmental, Underground excavations, basements and subways

INTRODUCTION

In the last 20 years building construction activity in most of the major cities has been on the rise. With effect, vacant and garden plots, sites with natural depression, ponds, etc., which served to hold the run off in a heavy downpour are now reclaimed and occupied by structures. Such situations coupled with blockages of old drains as well as the collapse of these drains lead to water logging problems. Moreover, the present construction practice is such that the open spaces between the building and plot boundary are covered fully with paver blocks or lean concrete. As a consequence, the component of run off which could have been absorbed by the soil cover is appreciably reduced. The net result of all these elements is a large increase in magnitude of runoff on the roads to be catered for by storm water drains. This leads to flooding of areas, bursting of underground storm water drains and even at times collapse of old buildings as well as basements, which are under construction. Such a severe water logging problem has necessitated widening and deepening of natural drains and existing system of drains.

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The construction for widening and deepening has to be carried out in the crowded neighborhood and/or in close vicinity of the unauthorized slums which pose a serious constraint on open spaces required for deep excavations.

For all these types of constructions like car parking, subways, widening and deepening of drains excavating deep sections is necessary. The methods deployed presently are either extremely costly or cause great hinderance to traffic and public movement.

PRESENT METHODS ADOPTED

At present the construction of deep excavations is achieved by one of the methods, described briefly below. The advantages and limitations of each method are discussed.

Conventional Open Excavation

This is the simplest mode of excavation. But the presence of high ground water table, non availability of adequate open space, and proximity of existing structures like buildings and roads, do not permit the constructor to resort to conventional open excavation while dealing with deep open excavations particularly in crowded urban areas.

At times it is possible to tackle the problem by taking small stretches of say 3 m length at a time. Even in this scheme the problems to be faced remain the same, but their gravity could be somewhat less because of the size. Another serious disadvantage is the uncertain time frame of the works due to problem of dewatering and stability of slopes. In this method the excavation is made first for a small stretch and then retaining element of the same length is constructed. Where the time is not critical, the method could be used subject to other conditions not posing serious problems.

Diaphragm Wall

The very widely used method for prestigious projects is construction of diaphragm walls as an enabling work. The diaphragm walls are either free standing walls or anchored diaphragm walls. In the grab method of boring as deployed in diaphragm wall construction, it is not possible to penetrate into even 'soft' rock so as to derive reactive forces to deal with the active forces generated by retained earth and as such resort to pre-stressed anchors is essential. These anchors are quite long and often pass through the adjoining properties in order to obtain required reactive force. Further, the inclination of the anchors not only increases the length of anchors but also adds a vertical force on the cross section of the wall. In the olden days, due to the unawareness of the general public, this aspect was overlooked and many a buildings with basements were constructed. But nowadays, such activity will lead to legal complications and heavy compensation.

The other aspect of diaphragm wall construction is the need of specialized agency possessing costly equipment. Due to availability of only a limited number of specialist agencies, constructing diaphragm walls becomes costlier.

The advantage of grabbing system is the construction of larger panels. Panel size of 5 to 6 m is quite common. The longer length of panels necessitates higher slump of concrete, necessitating concreting using at least two tremie pipes in one panel. The operation with two tremie pipes calls for a watchful eye to ensure coordination during concreting activity. The tendency to use only central tremie while constructing the diaphragm walls leads to extraordinary bulging of concrete. Diaphragm walls are relatively impermeable but are not absolutely 'Bone Dry'. Further the grab sizes available in market are limited and as such the structural engineers have to use the size available and modify the design to meet the structural requirement, which often adds to the cost.

In addition to the panel construction the provision of anchors and their stressing is a time consuming and costly affair. Mid level anchors, if required, lead to a break in the excavation activity. The free standing diaphragm walls necessitate chiseling operation for develop-ment of adequate socket length in rock. In case soft/hard rock is met above the scheduled basement excavation level, advancing the panels through weathered rock /soft rock is quite a task. It is because of all these difficulties that use of diaphragm walls is a costlier and time consuming proposal.

The construction of guide walls running to a depth of 0.5 m to 1 m (with minimum of 20 cm thickness) on both faces of wall all along the periphery of the diaphragm wall alignment for the entire length of diaphragm wall adds to time and cost.

Touching Piles

Another quite popular method is construction of touching/conjugate piles to serve as retaining elements. Many clients, engineers and planners opt for this method because of easy availability of contracting agencies. Since piling has become a very common activity, it is rather convenient to get an agency at a competitive price. But the serious disadvantage of the method is the excessive consumption of steel on account of circular nature of the piles to withstand the bending forces. Further to accommodate more steel and to ensure easy flow of concrete beyond the reinforcement cage, the pile diameter is required to be increased, leading to extra cost and consuming of more space and thus limiting the usable area. Socket for piles could be made into the rock with some difficulty depending upon the quality of the rock (of course at a cost). The touching piles system can serve only as an enabling work and requires the construction of regular retaining element with suitable water proofing features at a later date.

Box Pushing

For last 40 years, box pushing technique has been used with advantage for construction of subways particularly for Railway crossings. The technique of box pushing requires suitable space abutting proposed subway alignment for the construction of reaction blocks and casting of boxes. The method requires expert knowledge and special equipment. These parameters make the scheme costly. The initial preparation time for the construction of the reaction blocks and construction of precast boxes is quite appreciable.

The method is not suitable for subways located in crowded areas of metropolitan cities due to constraint of space and time and availability of suitable stratum. For basements, it is an extremely costly affair. As regards widening and deepening of *nallahs*, box pushing is not suitable.

METHODOLOGY OF CONSTRUCTION FOR METER PANEL SCHEME

Meter panel construction is done using the conventional piling rig (tripod), changing only the shapes of boring tools like bailer, chisel, bottom or guide casing. The use of conventional piling rigs makes the system cost effective. Depending on the time schedule, the number of rigs can be conveniently increased (which is a very important feature of the scheme) without much difficulty, as such rigs are easily available. The shape of the conventional circular piles is changed to rectangular shape. The tolerances of the tool are carefully planned so as to ensure the development of required size of the bore. The chisels and bailer of the required dimension can be easily fabricated. Another specific advantage of the meter panel system is that by just changing the tool size, the wall of structurally required width for a given retention can be constructed. The feature is of great importance in optimizing the design. Such an advantage is not available with a diaphragm wall as the fabrication of the grabs is a very costly affair compared to fabrication of cutting tools of the meter panel.

Construction Procedure

Excavate manually to a depth of 0.5 m to 1 m so as to lower the casing in the excavation made along the construction line of meter panel and then hammer the casing for a depth of 2 m. Guide casing of two meter length is sufficient to ensure verticality of the wall.

Boring can be commenced with the help of bailer. The weight of the bailer and its cutting shoe are the most important parameters for faster progress. In case of sandy formation the Direct Mud Circulation (DMC) method could be adopted. The bore is developed by the bailer or by DMC up to the hard stratum.

On reaching weathered rock, the bore is developed further with the help of specially designed rectangular chisel. Normally, in case of circular piles, chiseling is continued for half an hour and bailing is done for 10 min. But in case of meter panels, chiseling for a period of 20 min necessitates bailing due to the nature of the tool as it strikes or hits the same contact area over and over. The rectangular shape of the tool prevents change of direction of blows (which is possible for circular piles) and leads to increased quantum of chiseling efforts. In general, it is observed that the chiseling time for a given socket length for a meter panel wall is about 40% to 50 % more than that for equivalent conventional circular piles.

On reaching the desired founding level including the required socket, steel cage is lowered. The cover provided is minimum 75 mm to main reinforcement. It is very essential to make the steel cage sufficiently rigid by tack welding so that the cage does not deviate from its contemplated position. For a wall of 6 to 7 m depth, having retained height of 4 to 5 m the required steel is of the order of 70 to 80 kg/m^3 which is normal for a free standing retaining wall. On lowering the reinforcement cage, concreting is done with tremie. All precautions required for tremie concreting are to be scrupulously followed to ensure dense concrete.

The grade of concrete preferably should be M 25 and above. The water cement ratio should be kept between 0.4 and 0.45 by adding plasticizers as required. The slump of concrete should be around 160 mm, so as to have a self compacting mix. Since the meter panel length is restricted to 1 to 1.5 m, desired concreting can be done only by a single tremie. It reduces the pressure of moni-toring on execution agency. For meter panels in clayey soils, joints will not pose any serious problem of trickling of water. For sandy soils, joints will pose some problem which can be tackled by sealing the joint by nailing strip of precast concrete or steel plate or rubber seal with the meter panel wall similar to water stops in diaphragm walls.

After casting the first panel, alternate panel is taken up. In this fashion the work can be completed. Depending on the elbow space available, the number of rigs can be increased to meet the desired time frame.

The specifications for piles as outlined in IRC 78 or IS 2911 are to be followed while executing the meter panels.

APPLICATIONS OF METER PANELS

Meter panel type of construction can be easily deployed for developing deep basements even in crowded cities. Touching meter panels have been effectively deployed for widening/ diversion of Nalahs, natural drains, as well as subways construction. Each application of meter panel is dealt below:

About 200 basements, going as deep as 12 to 15 m, have been constructed in the city of Mumbai by using meter panels or touching piles. In the city of Chennai, just abutting Mount Road, the Indian Express Mall has a basement section going as deep as 17 m and the plinth area is also very large (about 1,000 of sq m.) The construction of this basement was accomplish by resorting to touching piles. With judicious use of well point system, deep excavation to the tune of 17 m was done by construction of touching piles of 900 mm diameter going to a depth of 23-25 m and adequately reinforced. Anchors were not provided.

Deep excavation of the order of 6 m and above in crowded metropolitan cities is a tricky affair. The promoter and user would prefer to use as much plot area as possible for the purpose of basement, so that maximum area is available for functional use. The open space between the plot boundary and the basement edge for deep excavations range hardly around 1.5 m in many of the cases in cities. Open spaces are governed by the norms of respective civic bodies.

In a majority of cases, the upper couple of meters of overburden is often reclaimed (particularly in cities) or weak in shear charac-teristics and deep excavations do not allow vertical cut of excavated wall for more than a couple of meters. In order to maintain the thickness of the retaining element to a minimum, it will be necessary to provide anch-ors and these anchors will be going through other properties. Such a situation is not acceptable to the owners of the adjoining properties even if the anchors are temporary. This eliminates the possibility of open excavation as well as diaphragm wall type of excavation system requiring anchors.

The Meter panel system is quite suitable for construction of basements in metropolitan cities. However, if basements are very deep and hard stratum in the form of rock is not available for very great depths and anchors can not be provided, then very thick panels with well point system to take care of water pressure need to be resorted to (The cost is very high for such a situation).

Application for Widening of Nallahs, etc.

There is a growing need for deepening and widening of nallahs flowing through metropolitan cities. Many a times major drains are also required to be widened and deepened. Protection of river banks can also be achieved by adopting meter panel technology. In this type of deepening and widening, many a times there is a huge constraint of available open spaces. In particular, in cities, there are slums located on the banks which are very difficult to vacate. At times, just along the banks of natural drains, roads are constructed for serving urban traffic. These are all situations which can ideally be tackled by resorting to meter panel technology.

One hundred kilometers of *Nallah* widening and deepening project has been completed by resorting to meter panel technology in the City of Mumbai in record time.

Meter Panel Construction With Specific Reference to Subways

Meter panel method can conveniently be adopted for construction of subways with great advantage. Meter panels can be constructed along the centerline of the proposed subway walls facing each other. Initially a portion of the road as per convenience of traffic can be tackled, keeping the balance portion open for traffic. For speedy construction more rigs can be deployed. The work may be started on a weekend so as to complete the construction of meter panel wall for say ¼ section of the road in three to four days. Immediately the slab spanning between the walls could be cast. It will not require any props or centering and shuttering as the soil below is not excavated. It will be more like reinforced pavement construction. Immediately on casting and curing of slab, bituminous macadam and asphalt road can be constructed and section opened for traffic.

After this, excavation can be taken up. In the next portion the meter panel walls may be constructed simultaneously. Meter panel walls may be provided with a liner wall of 15 cm from inside with suitable water proofing scheme.

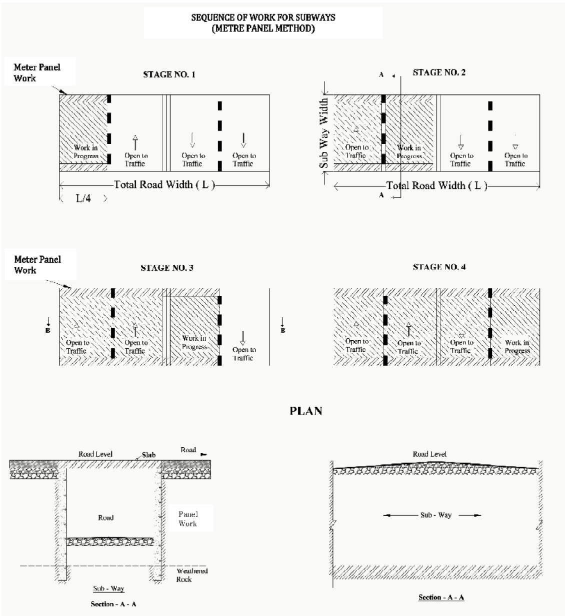
For the subways in business areas of the city, work may be commenced on a Friday after office hours. And in a period of two days even ½ of the road can be provided with meter panels plus slab. The other half may be tackled in the next weekend. Thus in business area, traffic problems can be minimized with this sequence of work of meter panels (Refer Figure 1).

The greatest advantage is minimum disturbance to the traffic. Subways across carriage ways in midst of city admeasuring 30 m to 60 m in width, construction can be completed in maximum of four months. Traffic obstruction at any time will be only for ¼ of cross section of road for a distance of subway opening plus 5 to 6 m on either side. There will be considerable saving in cost and time, compared to other methods.

Design Principles

Meter panel wall is designed like conventional

Figure 1: Typical Subway Construction Sequences



free standing retaining wall without heel and toe. Instead of heel and toe the wall is provided with a socket into rock/soil as the case may be. The length of socket or the area of socket can be worked out by principles outlined in design of sheet piles/retaining walls. It is necessary to have a detailed soil investigation including finding out the C and ϕ characteristics of the overburden soil and Unconfined Compressive Strength (UCS) of rock.

Due to the rectangular nature of the meter panel it is possible to lower the rectangular cage with more steel on the retaining side and less on the side to be excavated.

Step I

Once the height of retention is known the active pressure exerted by the soil and water column can be worked out using the following equation.

$$P_a = \gamma_d \left(\frac{1 - Sin\phi}{1 + Sin\phi} \right) + water\ pressure - 2C \qquad ...(1)$$

C and ϕ are soil properties. The water pressure can be worked out on knowing the level of the ground water.

The active pressure diagram and the location of resultant active force can be plotted. If there is any surcharge loading the effect of the same should be considered by converting into equivalent height of soil column with $\phi = 30^0$ (Refer Figure 2 below).

Step II

The passive pressure can be calculated on knowing soil properties of the formation below by using the following equation:

$$P_p = \gamma_d \left(\frac{1 + Sin\phi}{1 - Sin\phi} \right) + 2C \qquad ...(2)$$

The full passive pressure shall commence after allowing for the transition of active pressure to passive pressure as per Figure 3.

The passive pressure *Pa* =*Pp*. The equilibrium as regards lateral force is achieved (Refer Figure 4).

Figure 2: Active Earth Pressure Diagram

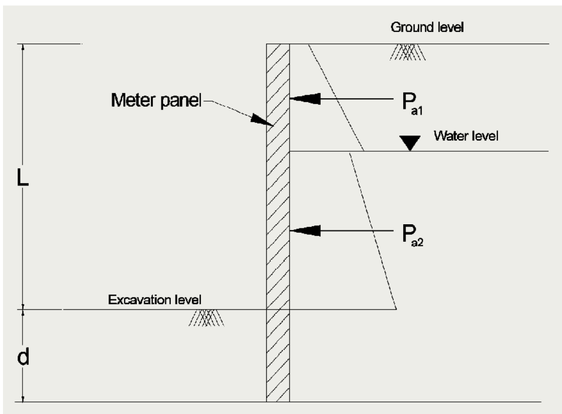


Figure 3: Active and Passive Earth Pressure Diagram

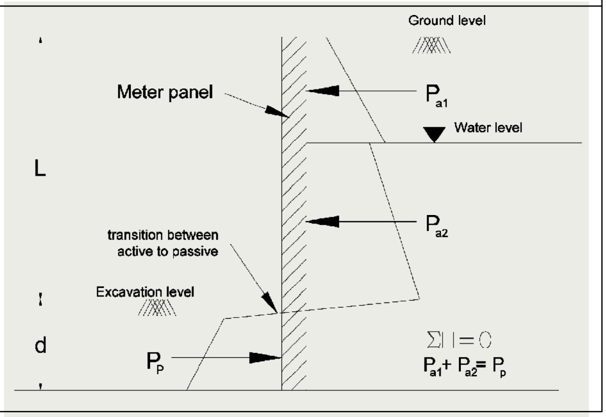
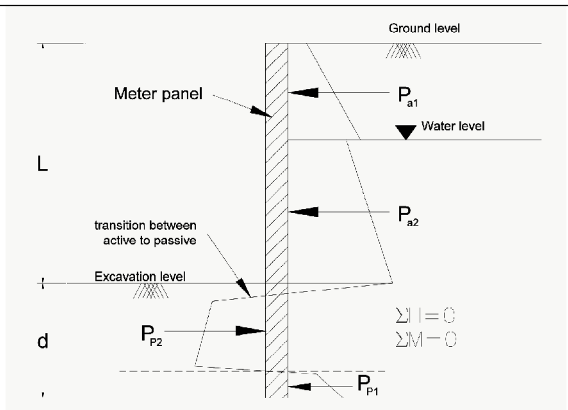


Figure 4: Equilibrium of Active and Passive Earth Pressure Diagram



Step III

From the step I and Step II it can be seen that for equilibrium condition all $\Sigma H = 0$ is satisfied but since these are two equal and opposite parallel forces they will induce a couple and the condition of $\Sigma M = 0$ has also to be satisfied for equilibrium.

The same can be achieved on generating a balancing couple on going deeper. In this process the passive area (I) has to increase as then the condition can be satisfied. This means trial and error.

If the soil investigation of strata is continued for a greater depth below the excavation bottom then initially for first trial purpose, a depth of 5 m can be considered below the passive area I and the trial error method followed for satisfying equilibrium.

In case soft rock with reasonable recovery and RQD, i.e., recovery up to around 50 % and RQD between 20% to 30% and UCS more than 3000 kN/m^2 is met, depth of 3 m may be taken below the passive zone area as the first trial. Within a couple of trials, the problem can be solved.

In case, good rock is encountered (recovery more than 60%, RQD more than 30%, UCS more than 5000 kN/m^2) then a depth of 2 m below the passive area may be the first trial value and then within a couple of trials the solution can be reached.

Step IV

Design the section of the retaining element using the grade of concrete and reinforcement.

Approximate Method

The design of meter panel can be done by following the approximate method adopted for design of sheet piles. The details of this method are given in many handbooks and technical literature on Foundation Engineering. The approximate method is described in detail in the chapter on sheet piles in book titled *Handbook on Foundation Engineering* by Hans F Winterkorn, F Y Fang.

This approximate method is empirical in nature. It is found to be quite satisfactory for design of sheet piles. But it is known that sheet piles cannot be advanced in rocky formation. The suitability of this approximate method for meter panels with socket in rock has therefore its own limitations.

Design of Subways

Since the subway scheme involves construction of top slab prior to excavation, prop support is offered. The design therefore can take advantage of prop reaction while calcu-lating the bending moments, etc.

TYPICAL CALCULATIONS

Case study at site of Beam Developers Pvt. Ltd., New Link road, Andheri West, Mumbai:

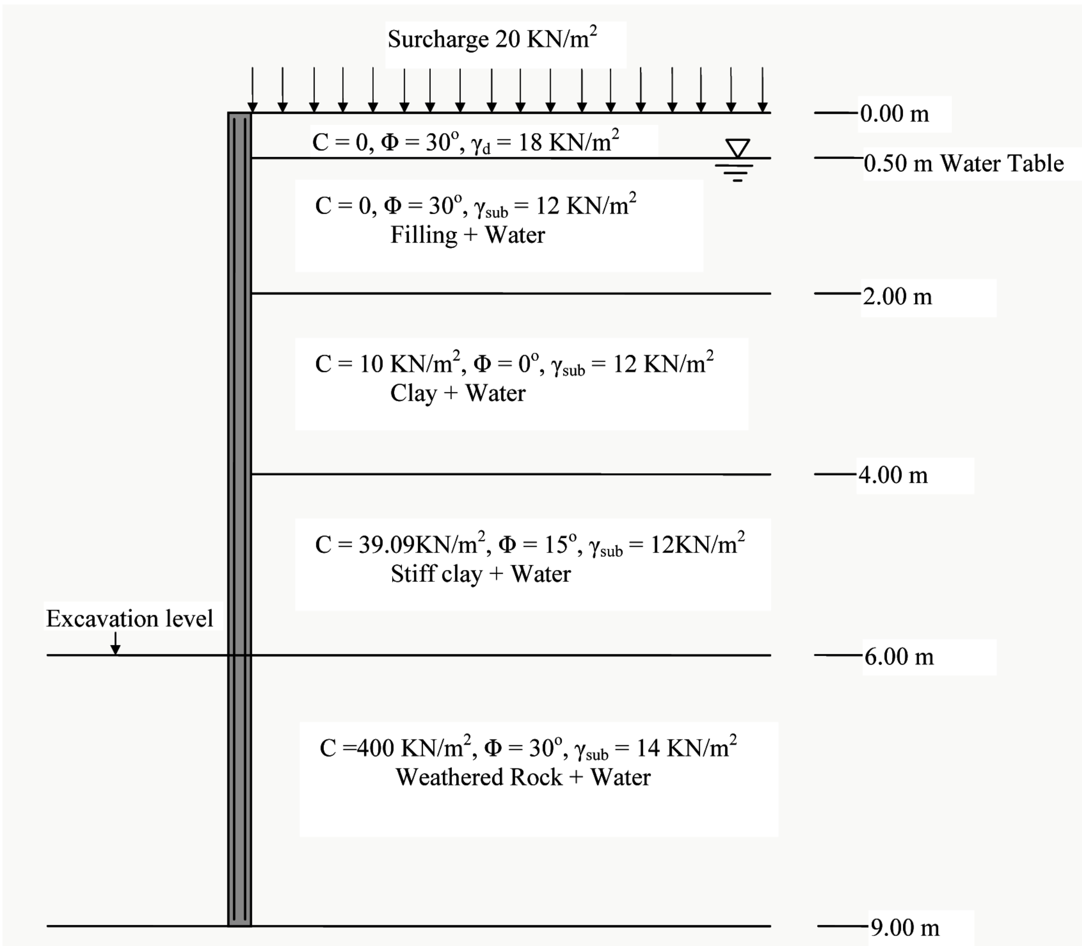
Soil Profile at Site

The observed soil profile at Andheri site is given as shown in Figure 5.

Required Data

- Ground water table: 0.5 m from original ground level
- Grade of concrete: M_{25}
- Grade of steel: Fe_{415}
- Depth of Excavation: 6.00 m from original ground level
- Plan Size of meter panel: 1000 mm X 600 mm
- Density of soil: 18.5 kN/m²

Figure 5: Soil Profile and Propreties at Andheri Site



Theoretical Behavior of Meter Panel at Andheri Site

In this section theoretical earth pressure, bending moment and shear force are calculated

Calculation of active forces from earth pressure diagram

Force	Magnitude in kN	Distance from 0.00 m
P_3	4.80	0.265 m
P_4	30.25	1.380 m
P_5	128.00	3.115 m
P_5	67.74	5.168 m

Earth pressures have been worked out as per Rankines formula

Sample Calculations

Active force $P_3 = \frac{6.7+9.7}{2} \times 0.5$

= 4.80 kN

at distance

$$X_3 = \frac{6.7 \times 0.5 \times 0.25 + 0.5 \times 3.0 \times 0.50 \times 0.17}{40.8}$$

= 0.235 m from 0.5 m level

= 0.265 m from 0.00 m level

Calculation of Passive Forces

Provide the panel socket from 6.54 m to 9.00 m, i.e., 2.46 m,

P_1 and P_2 are the forces acting at 8.40 m and 6.90 m levels respectively,

Taking moment about $P_{2,}$

P_1 (8.40 – 6.90) = 4.08 (6.90 – 0.265)

+ 30.25 (6.90 – 1.380)

+ 128 (6.90 – 3.115)

+ 67.74 (6.90 – 5.168)

P_1 = 530.57 kN

But, $\Sigma P_H = 0$

Therefore, $P_2 = P_1 + P_3 + P_4 + P_5 + P_6$

P_2 = 760.64 kN

The Pressure intensities at 7.80 m and 9.00 m are calculated as below:

Let Q_1 and Q_2 be the pressure intensities at 9.00 m and 7.80 m depth

Q_1 = 530.57/1.2 = 442.14 kN/m^2 < 2C; Hence Ok. Q_2 = 760.64/1.8 = 422.58 kN/m^2<2C; Hence Ok.

Theoretical Shear Force and Bending Moment Variation Along the Depth of Meter Panel

Table 1: Theoretical Shear Force and Bending Moment

Location from Ground Level in m	Shear Force in kN	Bending Moment in kN-m
0.00	0.00	0.00
0.50	4.10	0.96
1.00	10.70	4.52
2.00	34.09	25.76
3.00	87.09	84.55
4.00	162.09	207.30
5.00	186.21	380.22
6.00	227.38	585.38
6.54	0.00	654.80
7.00	–195.20	609.73
7.80	–531.92	319.99
8.00	–442.14	221.07
9.00	0.00	0.00

Maximum Theoretical Deflection

The deflection of the pile wall was calculated using moment area method. Therefore, the deflection of the top of the wall is given by,

Deflection at $x = 0$

$$\delta \text{ at top} = \frac{1}{4EI} \times (654.8 \times 6.54) \times \left(\frac{4}{5} \times 6.54\right) \quad ...(3)$$

where $E = 25 \times 10^6$ kN/m^2

$I = 0.018$ m^4

δ at top = 12.44 mm

< $L/250$ = 36 mm

Hence Maximum Theoretical deflection is within limits.

Design of Meter Panel at Andheri Site

The panel is designed for maximum bending and shear forces and reinforcement is worked out, which is as shown in Figure 9.

Precautions in Meter Panel Construction

The verticality of the wall is the most important aspect of meter panel construction. The verticality can be ensured by adopting DMC method for developing the bore or by ensuring that wire rope to which chisel/bailer is attached is always in the centre of rectangular guide casing at the top. It is essential to scrup-ulously monitor the verticality of the meter panel during construction.

During concreting it is advisable to take soundings regularly so as to know the build up level particularly, if depth is more than 10 m.

It is preferable to use temporary casing up to a depth of 3 m. As most of the subways are going to be less than 7 m in depth including depth of the road element, the problem of verticality is not so serious.

Other components of road construction can be carried out as routine.

Measurement of Deflections in Meter Panel Walls

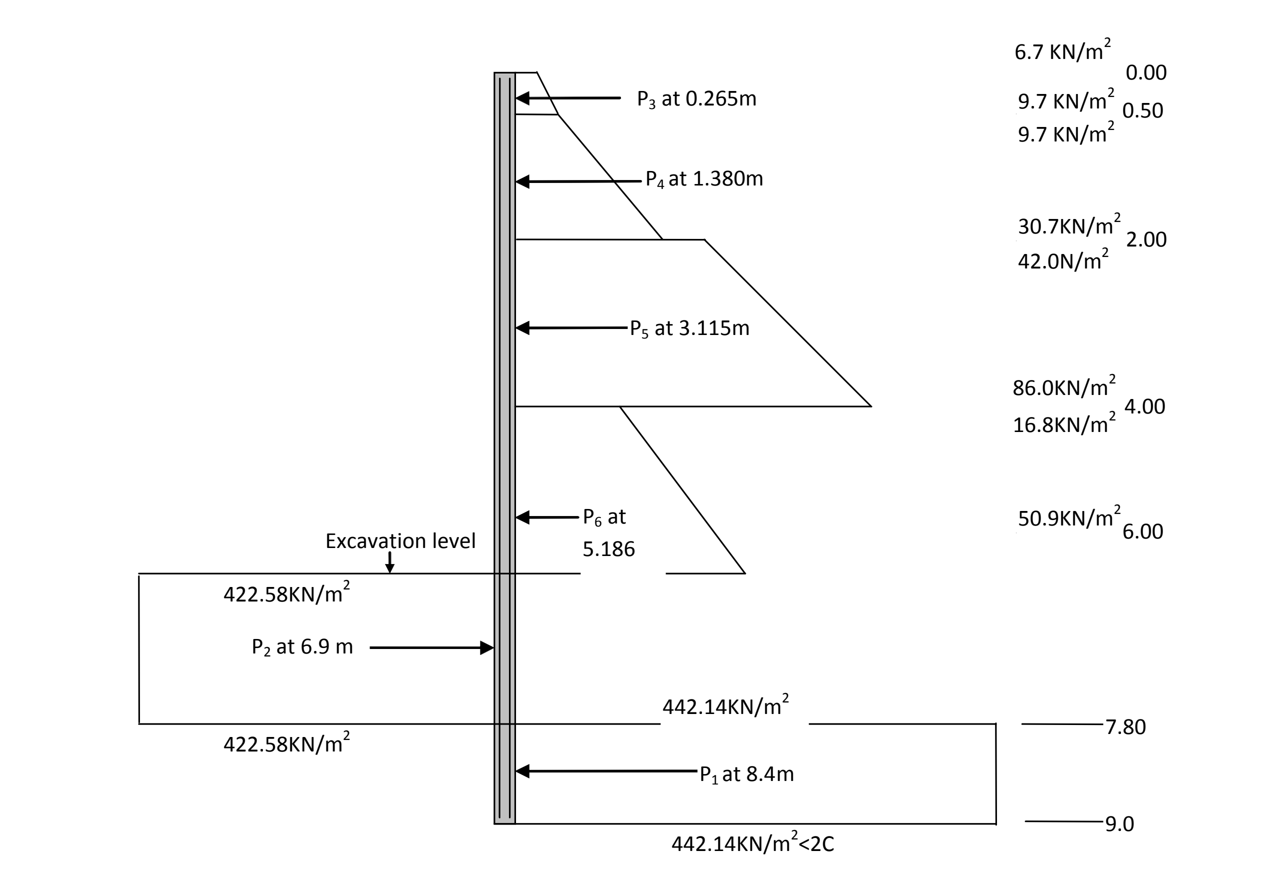
The behavior of meter panel can be monitored by measuring the actual deflection or the inward movement of meter panel wall between the excavated sides and comparing it with the theoretical deflection.

To measure lateral movement of earth work and structures, an Inclinometer is used. It provides the pattern of deformation, zones of potential danger and the effectiveness of construction control measures taken. Proper evaluation of inclination helps in monitoring the behavior after construction and indicates potentially dangerous conditions that may adversely affect the stability of the structure.

Apart from the deflection, the other important parameter of meter panel design is the moment it is subjected to. If the bending stresses developed are measured, then it will be possible to project a bending moment curve from the readings of bending strains collected during the excavation operation.

Another way of measuring deflection comprises marking the centre line on the capping beam with a Node Point at every 5 m. The vertical and horizontal co-ordinates of each node point can be established with the help of a total station before the commencement of excavation. These readings can be repeated on achieving standard excavation depth of the order of 3 m to 5 m. The difference between the two readings gives the inward

Figure 6: Theoretical Earthpressure at Andheri Site



Note: * Drawing not to the scale.

Figure 7: Theoretical Shear Force Diagram at Andheri Site

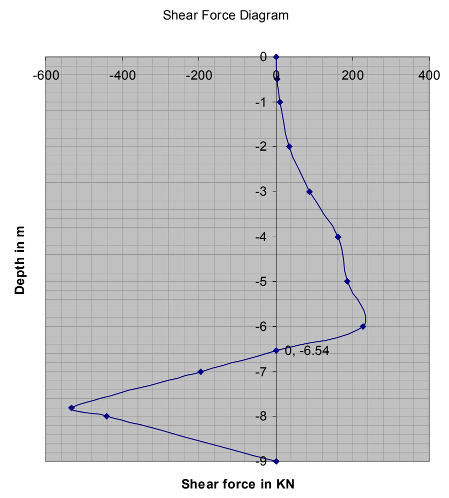


Figure 8: Theoretical Bending Moment Diagram at Andheri Site

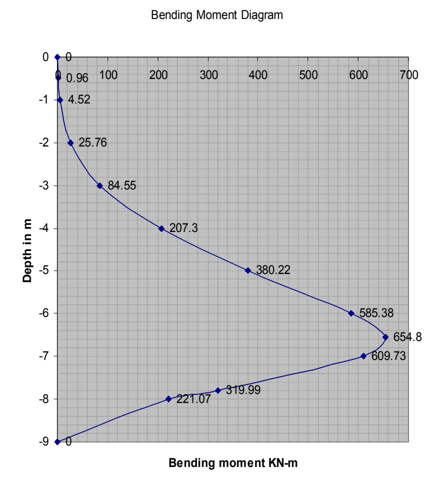
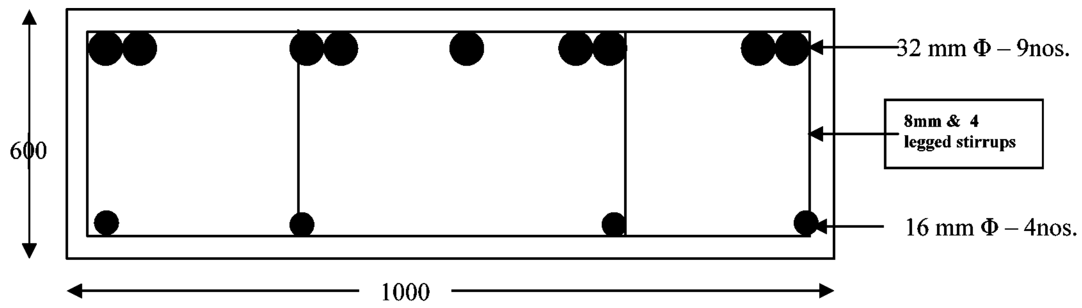


Figure 9: Detail of Reinforcement in Meter Panel at Andheri Site



movement of the wall towards excavation. This monitoring should preferably be continued till the comple-tion of underground construction activity and a good data will be available regarding the deflections.

CONCLUSION

i) From the discussion above, the innovative method is ideally suitable for the construction of subways in metropolitan cities or on busy expressways. The meter panel method is a cost effective and time saving method, causing minimum of obstruction to traffic.

ii) For projects involving river training where it is difficult to construct conventional retaining wall, the method provides the most suitable means to achieve the purpose of widening, deepening and bank protection.

iii) For basements in city areas, where deep excavation is not possible due to space constraint, the method is most suitable.

iv) The results have been analyzed using finite element programs and found to fairly tally with the theoretical predictions. Meter panel construction being an underground activity, the monitoring of meter panel behavior with respect to the deflections and deformations should be regularly done. Such an activity will give advance warning signals in case of any ensuing problems. Monitoring the behavior of meter panels also helps in getting a clearer understanding of the behavior of laterally loaded meter panels when subjected to actual loads.

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