Chapter 3

The Case Study

3.1 General Considerations

In this case study, two different areas were considered. They are:-

1. Swimming pools without a deep end
2. Swimming pools with a deep end

For each of the above cases designs were performed in conventional method and in the proposed method. These are presented separately.

3.2 Design of swimming pool without a deep end using conventional method

As explained in details in chapter 2.2 there are different types of swimming pools. This case study covers the design aspects of a swimming pool for a school, which is 25m in length and 12.5m in width. The water depths of the pool at the ends are 0.9m and 1.5m (Figure 3.1). There is a freeboard of 0.1m.Thus the heights of the walls at the ends are 1.0m and 1.6m respectively The design shall include all stability considerations, analysis of the structure to all possible load cases, design the structure for the ultimate load cases and finally checking of the structure for serviceability limit states.

It is to be noted that this study is aimed on swimming pools built on firm ground and the ground water table is 1m below the ground level. The following design data was used in the design of the swimming pool.

Density of water	= $10kN/m^3$
Density of earth	= $18kN/m^3$
Density of concrete	= $25kN/m^3$
Grade of concrete	= $30N/mm^2$
Grade of reinforcement	= $460N/mm^2$
Superimposed dead load on earth	= $5kN/m^2$

Bearing capacity of soil = $150 kN/m^2$

Friction angle = 30^0

Service moment from water = $\frac{10 \times 3^3}{6} = 45 kNm/m^2$

Horizontal pressure from earth = $18 \left[\frac{1 - Sin30}{1 + Sin30}\right]$

= $6 kN/m^2$

3.2.1 General arrangement of the swimming pool

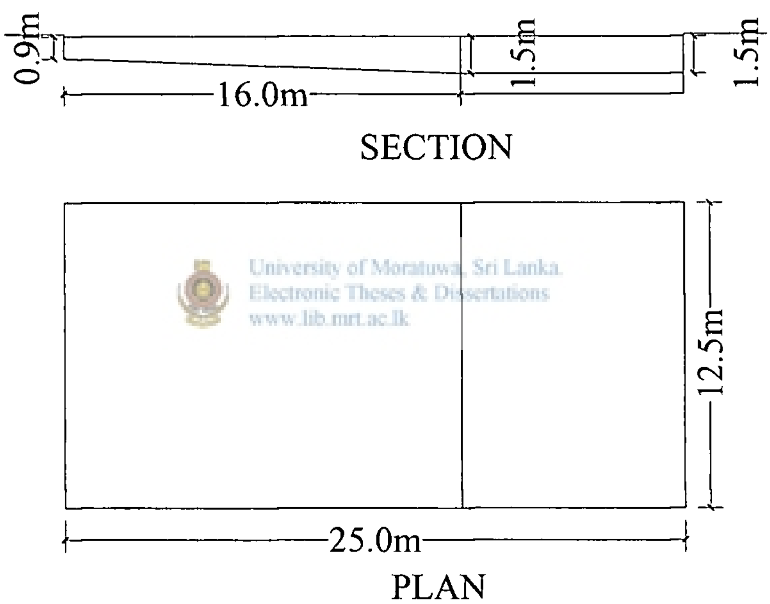

Fig 3.1:Plan and section of swimming pool without a deep end

Note : All dimensions shown above are internal

The structural design aspects of conventional swimming pool are first discussed and the design aspects of alternative swimming pool are presented thereafter.

3.2.2 Conventional swimming pool design

3.2.2.1 Wall design

The vertical walls of the swimming pools are designed as reinforced concrete cantilevers for pool empty and full conditions. When the pool is empty, the soil pressure is considered. When the pool is full, the pressure from the soil is ignored since this could be the situation when the water test is performed. The wall acts as a cantilever since it is rigidly connected to the base slab with sufficient width (300mm is favourable) to provide the weight and the rigidity required for the stability. The possible arrangement of joints in floor and walls are as below.

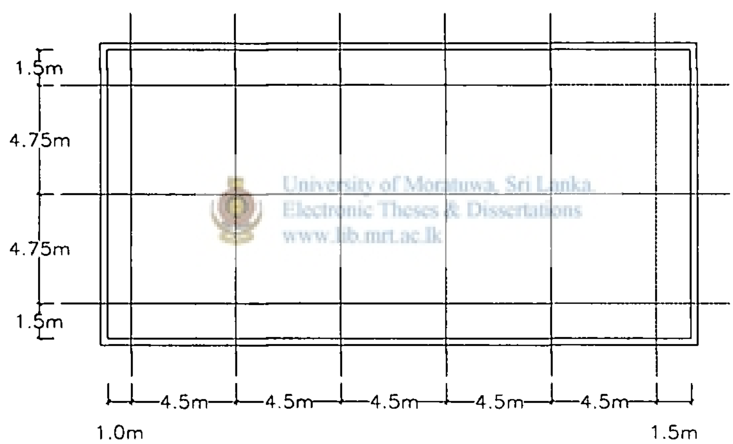

Fig 3.2:Possible arrangement of joints

The Figure 3.3 shows the cantilever wall arrangement in plan used for this study to minimize the complexity of the design using option 1 of BS 8007 with continuous construction of the base slab for full restraint.

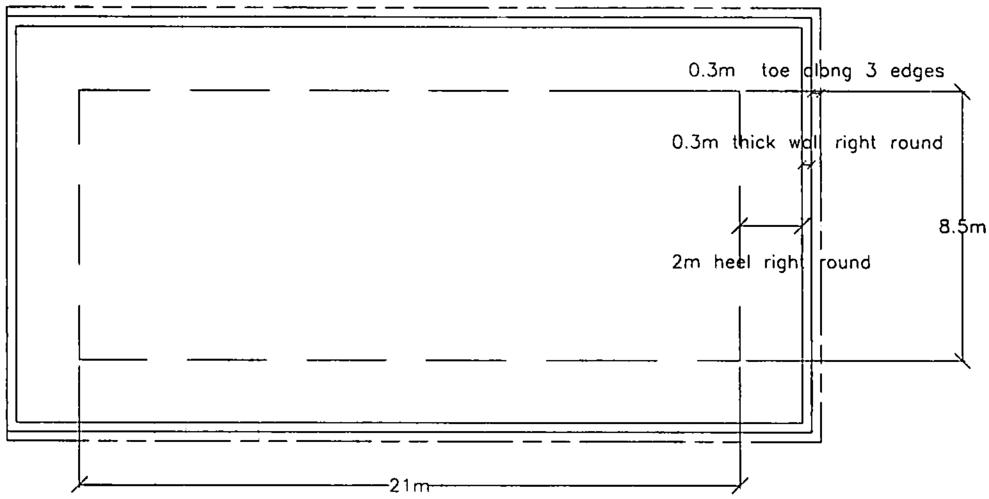

Fig 3.3:Arrangement used for the study

As seen form the above figure, a heel of 2m width and 0.3m thick is provided right round the periphery of the pool from inside. A toe of 0.3m wide and 0.3m thick is required along three edges of the pool for fulfilling the stability requirements (i.e : Toe is not required at 1.0m high wall edge).

All the necessary steps of design calculations for the pool without a deep end is included in the design for a pool with a deep end. Hence a separate design calculation file for a pool without a deep end is not included in this report. The comprehensive design calculation file for a pool with a deep end is attached as Appendix A. The design consisted of the following steps.

1. Check for stability of the walls for the three cases for tank full with no soil backfill, tank empty with soil & surcharge and tank full with soil & surcharge.
2. Check for soil pressure under the base.
3. Check for floatation.
4. Crack width calculation.

5. Design for ultimate moment.
6. Design for ultimate shear.
7. Check minimum areas of reinforcement for BS 8007 & BS 8110
8. Check for deflection.
9. Footing reinforcement.
10. Detailing of the joints.

The design calculation show that the walls require T 12 @ 200 c/c vertical and horizontal in each face. The heel along all the four edges and toe along the three edges require T 12 @ 200 c/c both ways top and bottom. The detailed drawings are given in Appendix C.

3.2.2.2 Slab design

As can be seen from Fig 3.3, base slab is 21m long and 8.5m wide and the base slab thickness is 0.3m to prevent floatation effects. The base slab is connected to the heel of the wall as a hinge along all four edges. When the pool is full, total downward pressure is resisted by soil pressure under the base. When the pool is empty, net pressure applied on the slab is due to the difference of self-weight of the base slab acting downwards and uplift force due to ground water. Upward force is less than the weight of the slab. Hence the slab is designed without taking the uplift force and it will be the most critical case to design the base slab. (i.e. the case if the pool is emptied for some reason during dry season where no upward pressure due to ground water).

This yields T12@175 c/c in short span direction at top of the slab. This reinforcement is sufficient for the prevention of the thermal and shrinkage cracking according to figure A.2 of BS 8007.. Prevention of thermal & shrinkage cracking in long span requires T12@175 c/c as the top reinforcement.

The slab is 300mm thick which needs the bottom surface zone of 100mm thick to be considered to resist thermal and shrinkage cracking according to figure A.2 of BS 8007. The bottom r/f of T 10 @ 200 c/c both ways will be sufficient for bottom surface zone.

Horizontal ties (T12 @ 200) are provided to take the vertical reaction between base slab and the heel of the wall. These same ties provide resistance to horizontal movement of the wall due to horizontal force on the wall due to water pressure

3.2.3 Detailing of the joints

All the wall and base slab joints are detailed as fixed joints as shown in Appendix C. Sample drawing of a joint between wall and base slab is shown in Fig 3.4 below.

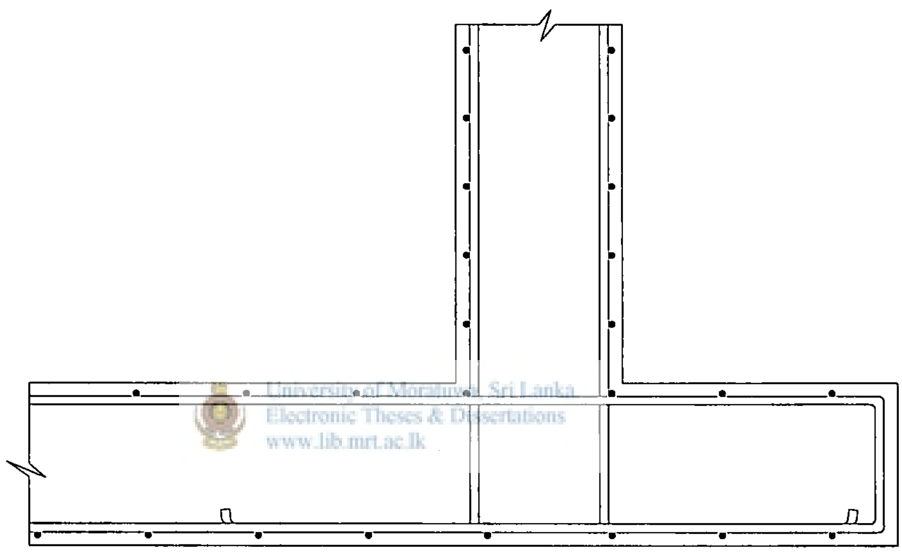

Fig 3.4:Fixed joint between wall and base slab

3.2.4 Summary of Structural arrangement

As mentioned in paragraph 3.2.2, detailed calculations for the pool without a deep end is not included in this report since all the design steps are presented in the calculation file for the pool with deep end which is annexed as Appendix A. Summary of the calculations are tabulated in Table 3.1.The design was performed to following codes of practice

BS 8110:1985 British standard code of practice for
Structural use of concrete

BS 8007:1987 British standard code of practice for
Design of concrete structures for retaining aqueous liquids

Component	Concrete thickness	Main reinforcement	Transverse Reinforcement	Additional components	Drawing Reference
1.1.6m deep wall	300mm	T12 @ 200 e.f	T12 @ 200 e.f	2m heel 0.3m toe Formwork-b.f	Appendix C Page A-42
2.Wall of varying depth from 1.0mto1.6m	300mm	T12 @ 200 e.f	T12 @ 200 e.f	2m heel 0.3m toe Formwork b.f	Appendix C Page A-42
3.1.0m deep wall	200mm	T12 @ 200 e.f	T12 @ 200 e.f	2m heel Formwork b.f	Appendix C Page A-35
4.Base slab	300mm	T12 @ 175 top T10 @ 200 bottom	T12 @ 175 top T10 @ 200 bottom	_	Appendix C Page A-46

Table 3.1: Summary of reinforcement for pool without a Deep end

3.2.5 Design Drawings

Design drawings for the conventional pool without a deep end is presented in Appendix C.

3.3 Design of swimming pool without deep end - Proposed method

3.3.1 Need for an alternative structure

The cost of construction of the conventional pool includes 300mm thick concrete walls, high reinforcement quantities, and formwork for both sides of the walls, 300mm thick concrete base slab, high reinforcement quantity for the base slab. The objective of this study is to construct the walls and slab of the pool at a lower cost while satisfying the basic requirements for a swimming pool as mentioned in section 1.1. Generally gravity type retaining walls would be sufficient to fulfill the structural requirements of the walls. Random rubble masonry is used as material of gravity type retaining walls as described in Appendix B. The specific requirement of the walls to be watertight will be met by constructing reinforced concrete lining wall from inside the random rubble masonry walls. Random rubble masonry walls act as outside formwork to these walls. As explained in the next paragraphs, base slab for this proposed pool will be 150mm thick with relatively less reinforcement amount compared to the base slab of the conventional type swimming pool. The base slab of this proposed alternative has no discontinuity of the slab as required for the heel/slab hinge arrangement in the conventional pool as describe in section 3.2.2.2.

3.3.2 Use of gravity wall type swimming pools for Sri Lanka

When gravity type swimming pools are designed, the following issues should be addressed (Jayasinghe,2001):

1. The possibility of water table rising outside.
2. The prevention of any lateral (outward or inward) movement of gravity walls.
3. The type of materials suitable for gravity walls.

3.3.3 Solution for the rising water table

In the gravity type swimming pools, the ground floor slab is not designed to withstand the hydrostatic pressure exerted by the high water table. Therefore, it is necessary to ensure that the water table remains sufficiently below the swimming pool floor. Ensuring a part of the swimming pool is located above the ground can quite easily satisfy this condition. For example, for a depth of 1.6m, 0.6m could be below ground. The remainder can be above ground. It is quite unlikely for the water table to rise to within 0.6m in laterite soil, unless in a low-lying area. Even if it rises, the self-weight of the base, which consists of 75mm screed, 150mm base and further 25mm for finishes, would be able to balance the upward thrust. This weight is about $6kN/m^2$ whereas the upward pressure is also $6kN/m^2$.

3.3.4 The prevention of lateral movement of the wall

Since any minute inward or outward movement of the gravity wall can cause leakage of water, it has to be prevented. The easiest way is to firmly anchor the wall by locating it over the ground concrete slab. Having a projecting key below the retaining wall can further enhance the anchoring effect. The starter bars for the concrete walls also can be fixed prior to laying of concrete for the ground floor slab.

3.3.5 The material for the gravity wall

One material that could become a strong candidate for the gravity wall is random rubble masonry. It is recommended by Chandrakeerthi (1998) that the random rubble masonry walls should be constructed with 1:5 cement sand mortar. The characteristic compressive strength that can be expected is about $2.0N/mm^2$. It is not advisable to rely on the tensile strength. It is also not possible to rely on the random rubble masonry for impermeability since it could be quite permeable through the mortar joint. Therefore, the concrete lining should be constructed with adequate precautions to avoid any weak or honeycombed concrete.

3.3.6 Structural design aspects of the proposed structure

The main structural components of the proposed arrangement consist of the following:

1. The random rubble masonry gravity retaining wall.
2. The reinforced concrete ground slab.
3. The reinforced concrete sidewalls.

The structural concepts and the additional precautions to be taken for each component are described in detail.

3.3.7 Design of the random rubble gravity wall.

The random rubble gravity wall has to be designed for the lateral pressure due to water. The size of the retaining wall is selected so that no tension will occur in it due to the flexural stresses induced as a result of lateral loads. The dimensions of the wall suitable for 1.5m depth indicated in Fig 3.5 were selected on this basis.

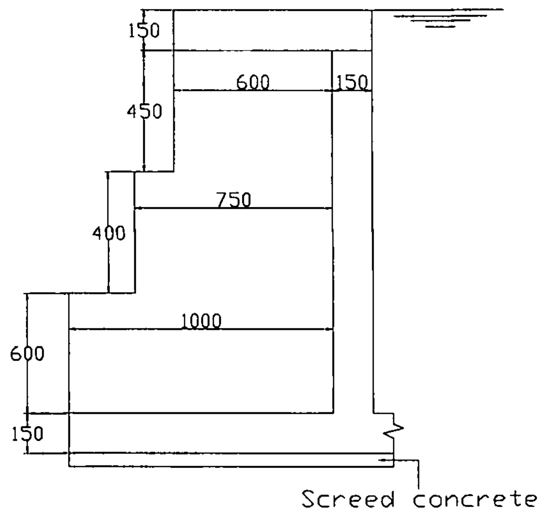

Fig 3.5:Section of wall of 1.6m deep

Random rubble walls require joints when the length is more than 15m. However, in this wall, the length is 25.0m. Therefore, it is advisable to have a strategy to prevent any cracks due to shrinkage although it is unlikely in this particular case. One strategy is to construct the wall in lengths of about 12.0m while keeping gaps of 1.0m. (This is anyway optional, provided good workmanship is available. Otherwise filling between two adjacent walls may lead to porous finish). When the wall is about 2 weeks old, the gaps can be filled up so that a portion of shrinkage has already occurred, thus reducing the chances of cracking. Once the concrete lining is cast, the possibility for shrinkage cracking is extremely remote.

3.3.8 Design of the wall

The reinforced concrete wall is cast by using the random rubble gravity wall as the formwork on one side. Therefore, the same method adopted for the floor can be used to determine the reinforcement to restrict the crack width in immature concrete. Since plywood formwork would be used as the shuttering on the other side, the value of T_1 should be $25^0C + 10^0C$ (Table A.2 of BS 8007).

In C1.A.3 of BS 8007:Part 1, a restraint factor, R is introduced with R = 0.5 for immature concrete with rigid end restraints. Since concrete is cast against the random rubble wall, it is advisable to use the value of R as 0.5. It was suggested by Fonseka (1995) that the use of the maximum value for R would be beneficial in Sri Lanka since any error in estimating the value of T1 would be adequately compensated. The use of minimum steel ratio of 0.0035 would result in a crack width of 0.167mm (<0.2mm). Therefore, the provision of 0.0035 as the reinforcement ratio is sufficient.

3.3.9 Reinforced concrete ground slab

The reinforced concrete ground slab need not have any flexural strength since the weight of water can be resisted by the soil below. Therefore, it needs reinforcement only to prevent early thermal cracks in immature concrete. BS 8007: 1987 allows the prevention of early thermal cracks in continuously cast concrete member by the provision of adequate amount of small diameter bars. It also allows the provision of this reinforcement in a single layer. In this type of construction, it is advisable to compact the soil below the ground floor slab thoroughly to avoid any weak pockets of soil prior to laying the screed concrete.

For the design of the reinforcement in the slab, the crack width allowed should be taken as 0.2mm. Equation 1 gives the maximum spacing of the cracks:

$$S_{max} = \frac{f_{ct}}{f_b} \times \frac{}{2\rho} \qquad \text{Eq. 1}$$

For deformed bars, $\frac{f_{ct}}{f_b}$, the ratio of the tensile strength of concrete to average bond strength is equal to 0.67 (Table A.1 of BS 8007: 1987). When a minimum steel ratio, ρ, of 0.0035 is used with 10mm diameter bars,

$$S_{max} = \frac{0.67 \times 10}{2 \times 0.0035} = 957\text{mm}$$

The corresponding maximum crack width can be found from Equation 2.

$$W_{max} = S_{max} \times \alpha \times \frac{T_1}{2} \qquad \text{Eq. 2}$$

The value of T_1 for the ground floor slab is $17^0 + 10^0 = 27^0C$. The value recommended in BS 8007: 1987 for T_1 is 17^0C (Table A.2). An additional 10^0 C is allowed for seasonal variations.

$$W\text{max} = 957 \times \frac{10 \times 10^{-6}}{2} \times 27^0C \quad = 0.129 < 0.2\text{mm}$$

Hence, the provision of 0.0035 on the reinforcement ratio is sufficient.

3.3.10 The structural arrangement of the swimming pool without deep end using proposed method

On the basis of the calculations described above , the structural arrangement is shown in Appendix D. The reinforcement details are also given. Since, it is necessary to have a walkway of adequate width around the swimming pool, an embankment can be formed using the excavated soil. This embankment should be paved at the top to ensure that all the water collected will be drained and removed from the location of the swimming pool in order to avoid any build-up of hydrostatic pressure.

Using the cement stabilization can further enhance the stability of the earth embankment. It was reported by Jayasinghe & Perera (1999) that it is possible to achieve compressive strengths in excess of 1.0 N/mm^2 for blocks when about 2% cement is used for stabilization of laterite soil. Therefore, the use of cement stabilized properly compacted embankment would give a long lasting solution which is a pre-requisite for a swimming pool. The soil excavated from the site can be used for this purpose. For the cost calculation, this is not considered since the use of cement stabilized soil is optional.

3.3.11 Design drawings of the proposed pool without a deep end

Design drawings of the proposed pool without a deep end is presented in Appendix D.

3.4 Design of swimming pool with a deep end -Conventional method

3.4.1General arrangement

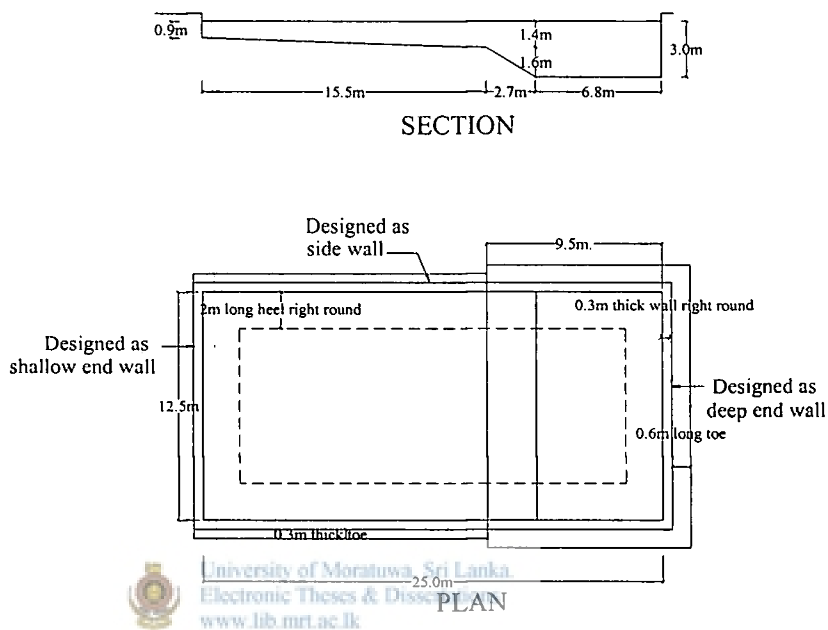

Fig 3.6:Plan and section of conventional swimming pool with a deep end

Conventional design concepts of swimming pools with deep end are very much similar to the design concepts of conventional of swimming pools without deep ends. The major changes are only the dimensional differences. In the design included in this study, the deep end wall detail is extended to the sidewall up to a distance of 9.5m from the deep end as shown in the above figure. Then it changes to a less strong detail called side wall and remains same up to the shallow end. The shallow end has another detail that is the weakest and it is called the shallow end wall. The complete calculation exercise is attached to this report as Appendix A.

3.4.2 The structural arrangement of the swimming pool with a deep end using conventional method

The detailed design was carried out using the same steps mentioned in 3.2 ,ie for pool design without deep end. The comprehensive calculation file is attached in appendix A. The detailed drawings are attached in appendix E.

The summary of the findings of the pool with deep end using the conventional method is tabulated below.

Component	Concrete thickness	Main r/f	Transverse r/f	Additional components	Calculation reference	Drawing Reference
1.Deep end wall	300mm	T16 @ 175 e.f	T12 @ 125 e.f	2m heel 0.6m toe formwork-b.f	Appendix A Page A-27	Appendix E-2
2.Side wall	300mm	T12 @ 200 e.f	T12 @ 200 e.f	2m heel 0.3m toe formwork b.f	Appendix A Page A-42	Appendix E-4
3.Shallow end wall	200mm	T12 @ 200 e.f	T12 @ 200 e.f	2m heel formwork b.f	Appendix A Page A-35	Appendix E-3
4.Base slab	300mm	T16 @ 175 top T10 @ 200 bottom	T12 @ 175 top T10 @ 200 bottom	_	Appendix A Page A-46	Appendix E-5

Table 3.2: Structural arrangement of the conventional pool
With a deep end

3.4.3 Design drawings of the conventional pool with a deep end

Design drawings of the conventional pool with a deep end are presented in Appendix E.

3.5 Design of swimming pool with a deep end - Proposed method

3.5.1 Need for an alternative method

The concepts highlighted in Section 3.3.1 are still valid in looking for an alternative method to design a swimming pool with a deep end. The same arguments for designing the walls and the slab provide a cost effective solution. Random rubble masonry sections obtained for the deep end require 2.4m widths at bottom. This section does not gain the expected cost savings and it is very inconvenient to go for sections of that much wide. Supply and storing of huge material quantities make inconvenience to other site arrangements as well. Further investigations diverted the study to use counter fort retaining walls for the deep end, which would be structurally satisfactory and less inconvenient than larger rubble sections. The other common features of the proposed method without a deep end discussed in Section 3.3 are not presented here to avoid repetition. Design and detailing of shallow end and sidewalls up to a total depth of 1.5m will be identical as swimming pool without a deep end.

3.5.2 Counter fort retaining walls at deep end

The length and height of the deep end are 12.5m and 3.1m respectively. A reinforced concrete wall of 150mm thick, simply supported at top and bottom bears the triangular load exerted by water pressure. This thickness is minimum required for the structural requirements. This has to be increased to 175-200mm due to constructional requirements.(4 layers of T10 reinforcement bars are to be provided). Cost study in Chapter 4 has been done taking this thickness as 175mm. As can be seen from Fig 3.7 below, this wall rests on 750mm deep beam at the top (i.e. the walk way slab) and the bottom slab vertically.

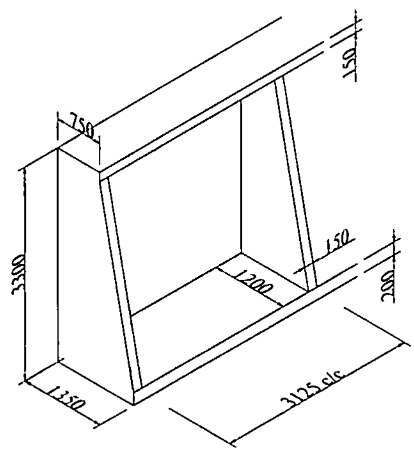

Fig 3.7:Dimentions of the counter fort retaining wall
Used to retain water at deep end

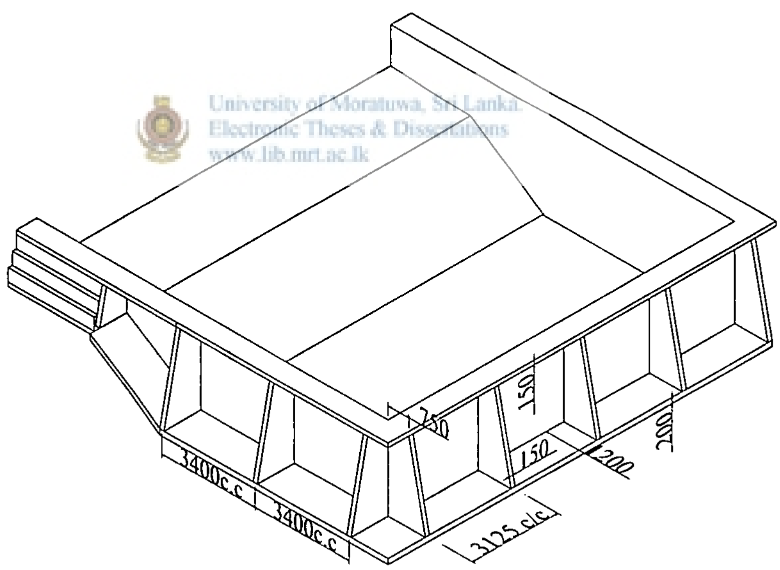

Fig 3.8:General arrangement of the counter forts

This wall spans horizontally between counters forts placed at 3.125m centers (5 counter forts totally for 12.5m long deep end wall). Thus the slab spans two-way to withstand the triangular load exerted by the water pressure. The moment applied to the wall is very small compared to the load on cantilever deep end wall in the conventional swimming pool. The crack width of wall needs to be checked over the vertical supports for hogging moment where cracks open to water contacting side. Nevertheless the crack widths are calculated in the outside faces to verify any possibility of exceeding the allowable limits. That calculation shows there is no such exceeding of crack widths and hence no harmful effects will occur due to ground water outside. This service moment is very small and the reinforcement requirement is T12@200 c/c at the inner face horizontally. Inner face vertical & outer face vertical & horizontal reinforcement requirement is T10@250 centers. These quantities are very much lesser compared to the reinforcement requirements for the cantilever deep end walls of the conventional swimming pool. The counter fort is designed as flanged cantilever T-beam with varying depth. Links have to be provided adequately between the wall slab and counter fort and between the base slab and counter fort to avoid tearing off.

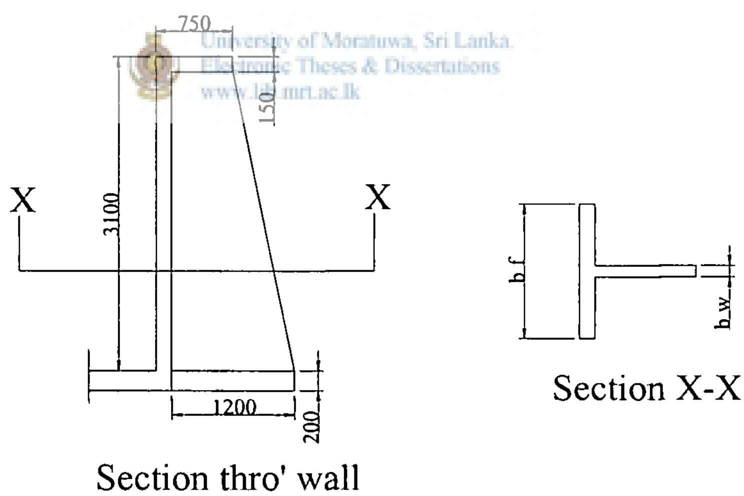

Fig 3.9: Dimensions of the counter fort

T10@175 for both faces vertical & horizontal will be sufficient as the links of the counter fort.

Pressure exerted on the counter fort is calculated by dividing the height into ten equal horizontal segments. This pressure is transferred to the base through a heel of 1.5m long and a toe of 1.2m long.

The longitudinal walls of the deep end are also provided with counter forts of this sort at 3.4m centers (Refer Fig 3.8).

3.5.3 Reinforced concrete ground slab design

The base slab is of two thick nesses. One part is 150mm thick as shown in the fig 3.10 below (slab A). Slab B is a combination of the foundation of the counter fort of 250mm thick (of a heel of 1.5m long and a toe of 1.2m long) and a middle portion of 150mm thick.

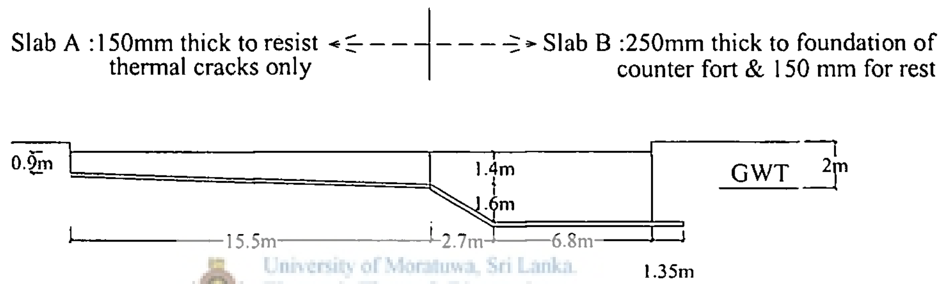

Fig 3.10:Section of pool showing slab thick nesses for design

Slab A is designed as in section 3.3.9 only to resist early thermal cracks in immature concrete.

Foundation of the counter fort is designed considering all possible load cases on the wall. The arrangement of reinforcement of the base of the counter fort is shown in Fig 3.11.

The rest of the slab B is of 150mm thickness.

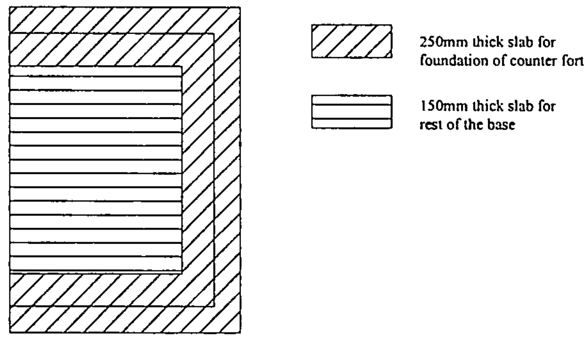

Fig 3.11:Base slab arrangement

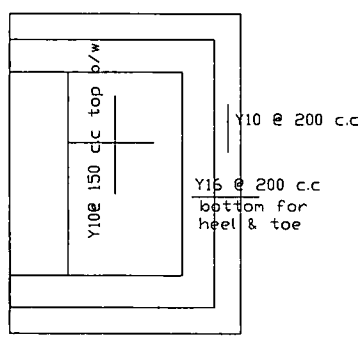

Fig 3.12:Base slab reinforcement arrangement

3.5.4 Design Drawings

The drawings for the proposed pool with the deep end are in Appendix F.