5.1 GENERAL

The formulation of the finite element prediction tool described in the previous chapter has to be validated through experimental results. For this, experiments were conducted on small scale models of gabion faced reinforced earth walls. While doing so, an attempt was made to explore the possibility of reducing the cost of construction by using quarry dust as a gabion fill material.

The most attractive feature of the gabion walls is their cost effectiveness. Gabion walls can achieve around 30 - 60% savings when compared to RCC walls constructed in similar situations. Even though the structure is a cost effective one, it can be seen that the stone filling used inside gabion boxes increases the cost of construction. In this work, an attempt is made to examine the effects of replacement of the stone filling in the gabion boxes with a mixture of stone and rock waste. The use of rock waste would relieve some of the problems associated with its disposal and it may turn into an inexpensive and advantageous construction product. It can also be noted that there is an added advantage in the use of rock waste from the quarries in the sense that the otherwise colossal cost of the conventional retaining structures is reduced to a very low value. This chapter describes in detail the different experiments carried out for determining the load deformation behaviour of the walls using gabions with different combinations of fill materials as facing.

5.2 MODEL STUDIES

In gabion walls, gravity force (self weight) is the predominant stabilising force, which depends on the unit weight of the material (γm) used for construction, which in turn is dependent on the specific gravity (G) of the material by the relation, \( γ_m = G \gamma_w \), where \( \gamma_w \) is the unit weight of water. The specific gravity of rock waste is nearly equal to that of stone.
Therefore, gravity force is not affected by the replacement of stone with rock waste. Considering all these points, rock waste was selected as a substitute for stone filling in this work. To represent the rock waste in the model studies, quarry dust, which is one of the easily and cheaply available waste materials, was used. Similarly stone filling was represented by 20mm coarse aggregate filling inside the gabion boxes. Instead of the actual gabion wall with stone filling, the one with a combination of stone filling and quarry dust was considered for the studies. Five different combinations were tried by varying the quantities of quarry dust and stone filling. The experimental studies were carried out on two different model walls constructed at two different sites. The first set of studies was on a 1m high model gabion wall constructed in the field in the premises of College of Engineering, Trivandrum (hereafter referred to as Set I in the text) and the second set on a 60cm high model gabion wall constructed inside a steel tank of size 1m x 1m x 1m in the Geotechnical Engineering laboratory of School of Engineering, CUSAT, Kochi (referred to as Set II in the text hereafter). The model walls were designed according to the physical properties of the materials used for construction like sand (as backfill), coarse aggregate and quarry dust (as gabion fills) and steel mesh (for gabion boxes and reinforcement).

Load tests were conducted on model gabion retaining walls to study the deformation characteristics of gabion faced retaining walls. The purpose of this study was to find out an optimum combination of quarry dust and stone filling, to replace the stone filling in gabion boxes and thus, further reduce the cost of construction of gabion wall. For this, five different combinations of quarry dust and coarse aggregate were used in the gabion fill supporting the model retaining wall. The combinations were varied by percentage weight of the filling materials in gabion boxes. The five different cases were:

i. Coarse aggregate alone
ii. 70% Coarse aggregate + 30% Quarry dust
iii. 50% Coarse aggregate + 50% Quarry dust
iv. 30% Coarse aggregate + 70% Quarry dust
v. Quarry dust alone
5.2.1 Field model studies – Set I

Field model studies were conducted to study the lateral deformation behaviour for the first set of experiments. The site for Set I experiments was selected where a natural slope was available for retention purpose, inside the premises but away from the active campus of College of Engineering, Trivandrum to avoid disturbance of any kind on the experimental set up. The length of the walls was limited by bays built using bricks. Gabion walls with the different facing materials were constructed in between these bays.

The sand used for backfilling was uniform river sand, with properties: $G = 2.72$, $D_{10} = 0.18\text{mm}$, $C_u = 2.22$, $e_{\text{min}} = 0.56$, $e_{\text{max}} = 0.69$. The coarse aggregate used as gabion fill material had the properties: $G = 2.83$, $D_{10} = 18\text{mm}$, $C_u = 1.67$. The quarry dust which was also one of the filling materials in gabion boxes, had the properties, $G = 2.8$, $D_{10} = 0.12\text{mm}$, $C_u = 2.89$.

5.2.1.1 Construction of model gabion wall

In actual field practice, gabion boxes of various sizes are used for construction such as $1.5\text{m} \times 1\text{m} \times 1\text{m}$, $2\text{m} \times 1\text{m} \times 1\text{m}$ and $4\text{m} \times 1\text{m} \times 1\text{m}$. For the reinforcement purpose the base of the gabion boxes are provided with an extension. Generally 0.6 to 0.8 times the height of the wall is taken as the reinforcement extension including the base of the box. The extension and boxes act monolithically. Boxes are provided with a top cover and internal partitions called as diaphragms to prevent bulging of the box. The model gabion wall was constructed over a length of $2\text{m}$. The height of the wall was fixed as $1\text{m}$. The wall was constructed at a distance of $2.5\text{m}$ from the natural slope and the space was filled with sand, which acted as a backfill to the wall. Brick bays were constructed on either side to limit the length of the wall. Sixteen numbers of gabion boxes each of size $0.5\text{m} \times 0.25\text{m} \times 0.25\text{m}$ were used to retain the backfill. Model gabion box used for the work is shown in Fig. 5.1. Boxes were provided with an extension of $0.55\text{m}$ at the base. Top cover was also provided. Because of the small size of the box, diaphragm walls were avoided.
For the load tests, using coarse aggregate as filling material, the above described model gabion boxes were used as such. But for the quarry dust and other combinations of quarry dust and coarse aggregate as filling material, the inner sides of the gabion boxes were stitched with geotextile Terram 1000. Nylon wires were used for stitching. The geotextile prevents the escape of quarry dust through the mesh openings. The photograph of gabion box used for the combination fillings is shown in Fig. 5.2. Fig. 5.3 shows the cross section of the wall and Fig. 5.4 shows the photograph of elevation of the model gabion wall.
The ground was levelled and 5cm thick layer of sea sand was spread over it. The first layer of four boxes was placed on the levelled ground surface where the wall had to be constructed. The boxes were connected together with steel wires so that they behave as a single unit. The extensions of the boxes were spread over the sand layer. Boxes were filled with filling material corresponding to the cases considered. In the case of combination filling, the quarry dust and coarse aggregate were filled in the boxes after mixing them properly in the required proportions. Filling was done with proper compaction to achieve the required unit weight of 15 kN/m³.

After filling the boxes, the top cover was closed and tightly connected to the sides of the boxes using steel wires. Behind the boxes, geotextile Terram 1000 was placed in order to avoid the entry of granular backfill into the boxes. Then backfilling of sand was done up to the height of the boxes. The backfill sand was compacted in each layer to get an average unit weight of 17.6 kN/m³. Each layer of the fill was compacted to get the same density by controlling the weight of soil and thickness of layer. After levelling the backfill, the next layer of gabion boxes was placed above the first layer and the two layers were stitched with steel wires and the procedure was continued up to the required level. Since the height of the wall was fixed as 1m, four layers of boxes each of height 0.25m were placed to complete the construction. Markings were made on the front of each box of the facing unit for taking measurement due to surcharge loading.

5.2.1.2 Loading set up

After the construction of wall using gabion boxes loading was done with sand bags. Before placing the sand bags a concrete slab was placed over the retaining wall to enable the surcharge loads to give a uniform pressure as well as to act as a loading platform. Sand bags were placed in layers (Fig. 5. 5). Each layer constituted of 25 bags filled with sand. Each layer provides a surcharge pressure of 2kPa. The load for the first layer of sand bag (2 kPa) and load from the concrete slab (1 kPa) was taken as the seating load and the initial deformations were noted. An aluminium rod was placed above gabion wall,
supported by the brick walls of the bay. This was used as a reference mark to measure the deformations (Fig. 5.6). In order to measure the lateral deflection the outer edge of the aluminium rod was used as the datum point. A plumb bob was hung down vertical from the outer edge of Aluminium bar. Using a metre scale the initial position of wall and the changed position after loading, were measured. The difference between these values gave the lateral deformation at each point.

Fig. 5.5 Schematic sketch of the loading set up

Fig. 5.6 Deformation measurements (Set I)
In total, six layers of sand bags were placed one over the other, above the retaining wall. Thus at the end of loading a total pressure of 13 kPa was acting on the wall. After placing each layer of sand bag the loading was kept undisturbed till the deformations stabilized. Before placing the next layer of sand bags, lateral deformations were measured. For Set I experiments, the walls were not loaded to failure due to the practical difficulty of increasing the height of dead load.

5.2.2 Laboratory model studies – Set II

The Set II experiments consisted of studies on model gabion retaining wall constructed in a steel tank of size 1m x 1m x 1m in the Geotechnical Engineering laboratory of Cochin University of Science and Technology, Kochi. The tests were done using the funding obtained from Kerala State Council for Science, Technology and Environment, Trivandrum. Unlike the Set I experiments, in these experiments, the walls were loaded with strip load using hydraulic jack and the horizontal deflections were measured using dial gauges to get a better control over the loading and deformations.

The sand used for backfilling was uniform river sand, with properties: $G = 2.7$, $D_{10} = 0.2\text{mm}$, $C_{u} = 2.6$, $c_{\text{min}} = 0.53$, $c_{\text{max}} = 0.71$. The coarse aggregate used as gabion fill material had the properties: $G = 2.87$, $D_{10} = 16\text{mm}$, $C_{u} = 1.313$. The quarry dust which was also one of the filling materials in gabion boxes, had the properties, $G = 2.81$, $D_{10} = 0.16\text{mm}$, $C_{u} = 2.81$.

5.2.2.1 Experimental set up

The height of the wall was fixed as 0.6m and the dimensions of the boxes and basal extension were designed using the physical properties of backfill soil and steel mesh which were obtained from laboratory experiments. Sixteen numbers of gabion boxes each 0.25m long, 0.15m wide and 0.15m high and with basal reinforcement of 0.35m were used to retain the sand backfill inside the tank. The boxes were fabricated by stitching steel mesh panels to get the required shape. Fig. 5.7 shows the complete experimental setup.
Four such boxes were stitched one beside the other to form a layer such that they behave as a single unit. Four layers were placed one above the other to form the wall. The boxes were numbered as 1 – 16 continuously as shown in Fig. 5.8.a. The horizontal deformations at the front face of the wall were measured using dial gauges with magnetic base (travel 25mm, least count 0.01mm) at the circled points (eight numbers).

For the load tests using coarse aggregate alone as the filling material, the above described model gabion boxes were used as such. But for the cases where quarry dust is also used as filling material, the inner sides of the gabion boxes were stitched with geotextile Terram 1000. Nylon wires were used for stitching. The geotextile prevents the escape of quarry dust through the mesh openings. The filling material in the boxes was filled at an average unit weight
of 15 kN/m³. In this set of experiments, the combination filling was done in layers. The required proportion of quarry dust was placed as the bottom layer and the coarse aggregate as the top layer, the separation between the two being made using the geotextile material.

The backfill sand was compacted in each layer to get an average unit weight of 16 kN/m³. Each layer of the fill was compacted to get the same density by controlling the weight of soil and thickness of layer. After levelling the backfill, the next layer of gabion boxes was placed above the first layer and they were stitched with nylon wires and the procedure was continued up to the required level. Four layers of boxes each of height 0.15m were placed one above the other to complete the construction. The layers were also interconnected using steel wires such that the entire wall behaves as a single block. Markings with small metal strips were made on the front face of the circled boxes (Fig. 5.8.a) at the centre for taking deformation measurements with dial gauges. Schematic diagram of the test tank with loading setup is shown in Fig. 5.8.

5.2.2.2 Loading set up

After the construction of the wall using gabion boxes, loading is done using hydraulic jack and lever arrangement. The loading pattern used is of two-point loading acting on a 25mm thick and 0.2m wide strip placed over the sand backfill parallel to the gabion wall. Load was applied using a hydraulic jack, in increments of 3 kN till failure. After applying each increment, the load was kept constant till the deformations stabilized. Prior to next increment lateral deformations were measured using dial gauges.
5.3 RESULTS AND DISCUSSIONS

An account of the results obtained from the experimental studies is presented in this section. Set I experiments were loaded up to 13 kPa which included a seating load of 3 kPa and initial deformations were measured only after stabilisation of the deformations due to the seating load. For the Set II experiments, the wall was kept undisturbed for a day for the stabilisation of
post construction deformations and loading was done on the succeeding day in increments. The load - deformation measurements were noted till failure. The type of loading for the two experiments were also different, viz., surcharge loading was adopted for Set I experiments whereas strip loading was given for Set II experiments. However the results can be used for comparison purposes considering the trends shown by the curves.

5.3.1 Load deformation characteristics

The effective replacement of stone filling in gabion boxes by a cheaper material is the focus of the study and is done by comparing the load deformation behaviour of the five different walls constructed with the fill materials mentioned in Section 5.2. Figures 5.9 and 5.10 show the load deformation characteristics for the two sets of experiments in which the deformation is expressed in terms of a dimensionless quantity, top sway factor, $\delta_u$ which is defined as $u_t / H$ where $H$ is the wall height and $u_t$ is the top lateral deformation of the wall at the midsection. Although $u_t$ is referred as top lateral deformation, it is measured as the average of the lateral deformations at the centres of gabion boxes numbered as 14 and 15 in Figs. 5.5 and 5.8. From the figures, it can be seen that as the load increases, the lateral deformation also increases, as expected. The quarry dust filled gabion walls show more lateral deformation than that of the coarse aggregate filled gabion walls. The combinations showed intermediate deformations. This may be due to the low stiffness characteristics of quarry dust filled gabions. As a result, as the percentage of quarry dust increased, top lateral deformation also increased. The 50-50 combination shows a top lateral deformation less than that of quarry dust alone and 70% quarry dust and 30% coarse aggregate combination.
5.3.2 Bulging patterns

The variation of lateral deformation along the height of the wall which is termed as "bulging pattern", also show the behaviour of retaining walls. The lateral deformations at the mid length of the wall (u) in all the four layers at a specific load value were measured in the experiments to understand the behaviour of the fill materials in the wall facings. The bulging patterns are plotted with the sway factor, \( \delta_u = u / H \) along the x-axis and the wall elevation along the y-axis. The bulging patterns are studied for a uniform surcharge load
of 13 kN/m in the case of set I experiments (which is the point where the failure starts) and for set II experiments, a strip load of 60 kN/m, which is the least failure load, among the cases tested, as seen in Fig. 5.10.

Figure 5.11 shows the bulging patterns of the model gabion walls for different combinations of fill. As the percentage of quarry dust increased bulging was observed to increase. It is seen that, the top layer experienced more bulging than the lower layer for the first three walls with lesser quantity of quarry dust. The other two walls with larger quantity of quarry dust showed an intermediate bulging in the third layer. An inference can be made at this point that the walls with lesser quantity of quarry dust behave in a stiffer manner than the other walls with higher quantities of quarry dust.

The difference between the two sets of experiments lies in the loading difference and the mode of filling the boxes. Even with these differences, the results are found to be comparable near to the failure points. From this, it can be inferred that the mode of filling has no effect on the load deformation behaviour of the system. But the second mode of filling, i.e., filling in layers may be preferred in the field owing to the easiness in filling and higher permeability characteristics.

On quantifying the increase in top lateral deformation of the quarry dust filled walls with respect to coarse aggregate filled wall (Fig. 5.12), it is seen from both the sets of experiments that filling 30% quarry dust increases the top lateral deformation approximately by 35%. When quarry dust is increased to 50%, almost 70% hike is seen in the deformation value. In general, as the quantity of quarry dust increased, the deformation also increased.
Sway factor at 13 kN/m uniform surcharge load

(a) Set I

Sway factor (δv) at 60 kN/m strip load

(b) Set II

Fig. 5.11 Bulging of front face of walls

(a) Set I at 13 kN/m surcharge load  
(b) Set II at 60 kN/m strip load

Fig. 5.12 Increase in top sway
To understand the nature of deformation hike by the addition of quarry dust, a plot (Fig. 5.13) has been made between the percentage of quarry dust and the percentage increase in deformation values with respect to the coarse aggregate wall at different layers at the mid section of the walls in the two sets of experiments. A curve was fitted between the points and it is seen that the increase in deformation varies quadratically with the quantity of quarry dust.

**5.4 SUMMARY**

Experiments were conducted on small scale model walls in the field and in the laboratory to validate the formulation of the FE code and also to investigate the effects of replacement of the stone filling in the gabion boxes used as facing in gabion walls, with a mixture of stone and rock waste. To find an optimum mixture of stone and rock waste to be filled in the gabion boxes, walls were constructed with different combinations of stone and rock waste and were loaded to study the variation in the deformation behaviour of the system. Load deformation curves and bulging patterns were plotted for the different walls and it was seen that the deformations increased with the increase of quarry dust in the facing. Up to 50% replacement of stones with quarry dust, the walls behaved in stiff manner and with further addition of quarry dust the walls became flexible. There is a quadratic increase in the
deformation values with the addition of quarry dust. The mode of filling the gabion boxes has little effect on the load deformation behaviour of the system. But filling in layers may be preferred in the field because of the easiness in filling and higher permeability characteristics.

The results obtained from these studies are made use in the validation of the developed FE code FECAGREW, as described in the following chapter.