Chapter 11

SUMMARY AND CONCLUSIONS

11.1 SUMMARY

Retaining walls, one of the most important geotechnical structures, finds application in every nook and corner of the world. The primary purpose of these structures is to provide lateral support for soil or rock. Some of the more common types of retaining walls are gravity walls, counterfort walls, cantilevered walls, and mechanically stabilised earth walls. Among these, mechanically stabilised earth retaining walls have become more popular in the past two decades and it relies on the friction between soil and external intrusions made into the soil to resist the lateral earth pressure. They are also called as reinforced earth walls or reinforced soil walls.

Gabion faced retaining walls which are gaining fast momentum in construction recently are commonly built as either gravity walls or reinforced earth walls. A vast literature survey was conducted wherein it was found that the number of research works conducted on these type of walls is very much limited in number. This means that the construction boom is enhancing without understanding the actual behaviour of these retaining walls which is, of course, leading to catastrophic situations. These walls being semi-rigid in nature behaves differently from the rigid gravity walls and the flexible reinforced earth walls. Thus there arises an urgent need to study in detail the performance of gabion faced retaining walls which has been taken as the topic of the present thesis work. This study is limited to gabion faced reinforced earth walls as they are more suited to larger heights.

In order to understand the behaviour of any system with respect to any point in it, numerical analysis has been proved to be a better tool than experimental methods by many researchers. Among the different numerical methods, finite element method stands in the forefront due to its versatility in modelling different applications and complex behaviours. Hence in this study,
finite element method was used as a prediction tool to simulate the behaviour of gabion faced reinforced soil walls.

A vast literature survey was conducted, where in, it was observed that, there exists a gap in literature which deals with gabion faced retaining walls. Further, the literature studies were extended to understand how the experimental investigations, analytical studies as well as numerical modelling could be conducted on retaining walls in general and how they could be applied to simulate the behaviour of gabion faced walls. Published literature on gabion faced walls was seen to be very few in number and hence all the available literature and design manuals of manufacturers were compiled and presented. Limit state method for design and analysis of reinforced soil walls as per BS 8006 : 1995 was also studied in detail as a part of literature study, so as to apply it to the design of gabion faced reinforced soil walls.

A finite element code named as FECAGREW (Finite Element Code for the Analysis of Gabion faced Retaining Walls) was developed by the author in C programming language as the first phase of the study. Plane strain condition was used for the analysis. Isoparametric quadrilateral (four noded 2D) elements were used to model the soil medium and the gabion facing. The reinforcing mesh was modelled using truss elements (two noded 2D) and the soil–mesh interaction using zero thickness (four noded 2D) line interface elements. The non linear behaviour of soil was modelled using hyperbolic stress–strain relation and the failure was modelled using Mohr–Coulomb failure criterion. The gabion facing was treated to behave linearly but simulation of failure was made using Mohr–Coulomb failure criterion. The confinement of gabion mesh was modelled as apparent cohesion induced into the gabion fill material. Construction phases were also modelled to simulate the constructional behaviour of the walls.

The developed FE code was validated at each stage using published data from literature and the final validation was done using experimental studies on gabion faced reinforced soil walls constructed in the laboratory. Related experiments for determining the essential parameters for modelling were also
conducted in the laboratory. The experimental model studies were then extended to check the viability of using an alternate cheap material like rock waste in place of the costly rock boulders inside gabion boxes. For this two sets of similar experiments were conducted on walls of different dimensions, one inside the laboratory and the other in the field.

FECAGREW was then used to conduct parametric studies on a gabion faced reinforced soil wall resting on a soft foundation by varying some of the salient geometric and material parameters. The geometric parameters varied were spacing of reinforcement, length of reinforcement, width of gabion facing and height of gabion wall. The effects of gabion fill, gabion fill – backfill combination and the effect of reinforcement were studied in the material parametric studies.

Design charts were developed for gabion faced reinforced soil walls to fix the dimensions of the structure without the usual tedious and repeated calculations. For this dimensional analysis of salient parameters in the limiting failure conditions as per BS 8006 : 1995 were carried out. The results of the studies were expressed as a set of dimensionless parameters. Graphs were then plotted using these to derive the necessary independent parameters for each failure condition. These graphs can be used as handy design charts for the design of gabion faced retaining walls. Additional design charts were then developed from the material and geometric parametric studies as a supplement to these charts. A design example was also worked out to illustrate the use of the design charts.

Economic studies were also conducted to prove the cost effectiveness of gabion faced walls by collecting field data from 57 different sites all over Kerala and cost prediction models were proposed for different types of retaining walls.

The design charts developed as well as conclusions drawn from the studies are expected to aid the design engineers at site and complement the construction works going on through out the world.
11.2 CONCLUSIONS

The major conclusions drawn from the present studies may be grouped into four parts as:

i. General
ii. Conclusions based on geometric parametric studies
iii. Conclusions based on material parametric studies
iv. Conclusions based on economic studies

11.2.1 General

- A two dimensional non linear FE code is developed with the acronym FECAGREW which can be used as a good prediction tool for the behaviour of gabion faced retaining walls, as established by the validation through experiments.

- The experimental studies show that there can be 25% replacement of rock pieces inside the gabions by a cheap and locally available material like rock waste without much altering the stability of the structure. In cases where deformation can be allowed to a certain extent, even a 50 - 50 combination of rock pieces and rock dust may be used.

- Design charts were developed as design aids for the gabion faced reinforced soil walls based on the limit state method of design as per BS 8006: 1995.

11.2.2 Based on geometric parametric studies

- For any wall height, the ideal spacing of reinforcement may be fixed as, \( h = 0.1H \) to \( 0.2H \). (In case of gabion faced walls, the spacing of reinforcement is actually a reflection of the box height as the reinforcement is provided as the basal extensions of the gabion boxes. So if spacings have to be provided at values, smaller than the standard box heights, they should be provided as intermediate ties).

- The ideal reinforcement length for gabion faced reinforced soil walls may be fixed as \( 0.4H - 0.6H \) (as against \( 0.7H \) of reinforced soil walls with...
flexible facing), beyond which the deformation variations are seen to be constant.

- The facing width of gabion faced reinforced soil walls may be fixed as \(0.1H - 0.15H\), beyond which the effect of deformations and pressure are seen to be marginal. The facing width has negligible effect on the lateral forces developed in the backfill.

- The critical planes where the strip loading should not be placed are the beginning and end of the reinforcement lengths. The most ideal position for placing the strip loading is at least 1.5L away from the back face of the wall where \(L\) is the length of the reinforcement. If in any case, the strip has to be placed inside the reinforced area, the best position is that the start of the strip loading should be in the portion \(0.5L - 0.75L\) within the reinforced region.

11.2.3 Based on material parametric studies

- 25% of the gabion fill may be replaced with a locally available material in order to bring down the cost of construction of the walls.

- In places where deformation is not a major criterion, the 50 - 50 combination may also be recommended.

- Regarding the mode of filling, it is always better to provide the soft material as a core inside the middle portion of the hard material rather than providing the material in layers.

- As stiffness of gabion fill and backfill increases, wall deformation decreases, reinforcement strain decreases and average safety factor increases.

- When used as gabion fill material, all the types of igneous rocks exhibit similar behaviour with the best performance. The metamorphic rocks show a more or less fair performance when compared to the igneous rocks while the performance shown by the sedimentary rocks is very poor when compared to the other two types. Hence, igneous rocks may be
considered as most suitable for gabion fills. Metamorphic rocks if locally available can also be adopted, but sedimentary rocks may be discarded.

- Maximum strain exhibited by the reinforcement is only 1.05%, which is very much less than the permissible strain of gabion mesh which is 10%. This means that the reinforcement is safe against breaking failure for all the types of backfills and gabion fills.

- Addition of reinforcement of length equal to wall height and spacing equal to box height, shows a three fold increase in the failure load as well as four times decrease in the deformations with respect to the unreinforced case.

- On analysing the deformation behaviour of the reinforced and the unreinforced medium height walls, it was seen that the reinforced case shows earth pressure nearing an at-rest condition while the earth pressure in the case of an unreinforced wall exceeds the active condition even at the stage of self weight loading.

- The introduction of reinforcement inhibits the formation of the failure plane in gabion faced walls by redistributing the stresses in the system.

- The safety factor for reinforcement was seen to be maximum at the top portions and at portions away from the wall facing. This indicates that sufficient reinforcement should be provided near the facing of the wall and at the bottom for minimising the failure risks.

11.2.4 Based on economic studies

- Cost prediction models were developed for different types of retaining walls based on the data collected from 57 different sites all over Kerala, which could be directly used for the estimation of cost of retaining walls.

- 30 – 50% savings could be obtained by going in for gabion faced gravity walls while the percentage goes up to 60 – 70% for gabion faced reinforced soil walls.
Space requirements are minimum for gabion faced gravity walls and maximum for gabion faced reinforced soil walls among the wall types considered in the study.

From the cost breakdown studies, it is seen that the maximum share goes to the cost of gabions.

The use of gabion faced reinforced earth retaining walls is growing at an enormous rate. This growth is justified on the basis of excellent performance – to date, superb aesthetics, relative ease - of - construction and overall low cost. It is felt that these walls are completely justified in their growth at present rates, and when augmented by the results of the present studies will be the choice of all wall systems in the future. The present studies throw more light on the behaviour of gabion faced reinforced soil walls, which will increase the level of confidence in the practising engineers.

11.3 SCOPE FOR FUTURE WORK

In the present study, the behaviour of gabion faced MSE walls were examined under the action of static loads only. Gabion walls are flexible structures, which move away from the soil sufficiently to minimize the soil pressures under disturbing forces such as earthquake force. As a result they can be used effectively in regions prone to earthquake forces. Hence, the performance of these walls under the action of dynamic forces needs to be examined. Thus the study can be extended to problems involving forces that are dynamic in nature, like the earthquake forces.

Similarly, the backfill soil considered was non - cohesive and of dry nature. Since the cohesionless fill materials are becoming expensive, other alternatives like cohesive fills are being adopted. Hence future studies may be carried out on the effect of cohesive backfills on the behaviour of gabion faced reinforced soil walls by modelling the permeability and consolidation behaviour of these soils. Also, for almost all practical cases, the effect of ground water is an important parameter. Thus this aspect can also be examined in future works.