Chapter 7

GEOMETRIC PARAMETRIC STUDIES

7.1 GENERAL

The finite element formulation for the detailed analysis of gabion faced reinforced soil walls and the validation of the same based on experimental data as well as prior published data have been discussed in the previous two chapters. The results obtained were encouraging when a small scale model of the gabion faced retaining wall was analysed and compared with the experiment data. This fact motivated to undertake parametric studies, the aim of which was to study the influence of some selected geometric parameters on the deformation behaviour of gabion faced reinforced earth walls at the end of construction stage. Parameters chosen for the study were spacing of reinforcement, length of reinforcement, width of gabion facing and height of wall. For studying the effect of a particular parameter, the same alone was varied, keeping all the other parameters constant.

Conventional wall design procedures are primarily stress based and do not consider deformations separately. Reason for the same being, deformations are relatively insignificant for the typical conditions of wall geometry and loading for which the design procedures were developed. But in circumstances where walls with non-standard geometry or loading cannot be avoided, deformation criteria should be carefully considered. For example, the use of shortened reinforcement layers due to topographic or economic constraints will cause increased deformations which would otherwise become critical, if avoided. Walls with large external loading or sloping backfills, walls where performance criteria requires very small deformations etc., are some other examples where deformations have more or less equal importance to stresses (Chew and Schmertmann, 1990). Hence this work concentrates on deformation studies.
This chapter explains the analyses conducted on gabion faced reinforced soil walls of three different wall heights - 3m, 6m and 9m representing the low, medium and high walls respectively. FE studies were performed by varying the spacing as well as the length of reinforcement and the width of gabion facing. The effect of the position of strip loading on the behaviour of walls was also investigated.

7.2 SYSTEM ANALYSED

The system considered for the analyses is described in detail in this section. A gabion faced reinforced earth wall of height, H, is assumed to rest on a soft clay foundation. Most reinforced soil walls analysed to date are built on competent or stiff foundations (Bauer and Brau (1996), Ho and Rowe (1996), Ochiai and Fukuda (1996), Rowe and Ho (1997), Helwany et al. (1999) and so on). In this case, estimation of wall deformation does not need consideration of the external movements of reinforced soil mass, in addition to those resulting from the internal deformation. Consequently, this results in reduced outward lateral deformation at wall face with increasing reinforced soil system stiffness (Ogisako et al., 1988). Where as, a system resting on soft foundation is more liable to external movement due to the movement of foundation soil below and therefore is less stable. Hence, in this study, the gabion wall was assumed to rest on a soft clay foundation.

The reinforcement extending into the soil was assumed to be of same length throughout the height of the wall and was taken as equal to H in the basic system chosen for the parametric study. The wall facing at the bottom was assumed to have an embedment of 0.15H into the soft clay. Spacing of reinforcement, h, was taken as 0.08H and width of wall facing as 0.15H, for the basic system, considering the general design practice.

After the convergence studies, the mesh chosen for the analysis consisted of 2290 nodes with two degrees of freedom (u and v) at each node. Horizontal translation was restricted for the nodes on the left and right end.
boundaries and all the bottom nodes were completely restrained (Fig. 7.1). The extent of boundary of the system was fixed after studying its effect on the behaviour of the wall. It was found that the response of the wall became insensitive to the location of the boundaries when the front face boundary was located 2H (or more) from the wall face, the back face boundary at 4H (or more) from the wall face and the bottom boundary at H (or more) from the wall base.

The geometry of the model was kept the same for all the parametric studies and only the parameter to be studied was varied accordingly. The FE mesh was fixed such that the same mesh could be used for all the parametric studies performed. The deformation analysis due to self weight of the system was performed which is the most important static load on a retaining wall system. The results were analysed in terms of deformations and lateral pressures.

![Fig. 7.1 Finite element mesh used for the parametric studies](image)

The basal reinforcing mesh of the gabion boxes extending into the soil were modelled using 288 two noded truss elements with axial stiffness only, assuming linear stress strain relationship. The properties of the gabion mesh were determined in the laboratory by conducting tension tests on a sample
specimen of the gabion mesh obtained from Maccaferri Environmental Solutions, Pvt. Ltd., Mumbai, India. The properties are listed in Table 7.1. The gabion wall facing was modelled as a composite material assigning properties obtained from literature (Helwany et al., 1996). 96 four noded isoparametric quadratic elements with linear stress strain relation were used to model the same. Properties used for modelling are tabulated in Table 7.1. The cohesion induced by the gabion facing ($c_r$) was calculated using Eqns. 4.55 and 4.56.

<table>
<thead>
<tr>
<th>Table 7.1 Material properties adopted for parametric studies</th>
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<tr>
<td></td>
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<tr>
<td>Gabion mesh</td>
</tr>
<tr>
<td>2235000</td>
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<tr>
<td>Gabion facing (after Helwany et al. (1996))</td>
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<tr>
<td>12700</td>
</tr>
<tr>
<td>Soil</td>
</tr>
<tr>
<td>Backfill</td>
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<tr>
<td>Foundation soil</td>
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<tr>
<td>Interface</td>
</tr>
<tr>
<td>Backfill sand - Mesh</td>
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<tr>
<td>Foundation soil - Mesh</td>
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</table>

The region of analysis included the foundation soil also along with the backfill because the gabion faced retaining walls are usually opted when the ground is soft. The soil material was modelled using 2066 four noded isoparametric quadrilateral elements. The non linear stress-strain behaviour of soil was simulated using Duncan and Chang (1970) hyperbolic model.
following Mohr - Coulomb failure criterion. The backfill was assumed to be beach sand and the foundation was assumed to be clayey silt whose properties were determined and are listed in Table 7.1.

In reinforced soil structures, the main criterion adopted in the design is that the desirable failure mode is pullout failure rather than the breaking of reinforcement. This is because the failure due to rupture can reduce the shear strength of the structure to a very low value which may cause catastrophic effects to the structure (Jones, 1985). Hence the failure of reinforcement was not modelled here and it was assumed that the system does not fail by the rupture of reinforcement. The pullout failure of the reinforcement was modelled using four noded zero thickness interface elements at the top and bottom of the reinforcement. 564 interface elements were used in the study. The interface elements were also used behind the vertical face of the gabion wall in contact with the back fill (24 nos.), at the base and in the front face (foundation) in contact with the foundation soil (8 nos.). The interface elements were modelled such that the shear stiffness is governed by a hyperbolic rule similar to that of the soil model and related the interface shear stress and displacement. The properties of the interface elements were determined using large sized direct shear tests on the gabion mesh sample pasted on a wooden block fitted on the lower half of the shear box and the other half of the shear box was filled with the corresponding soil at the required density (as listed in Table 7.1).

7.3 EFFECT OF REINFORCEMENT SPACING (h)

It is a common practice in the construction of gabion faced walls to provide the reinforcement at uniform spacing. Considering the economic aspects, varied spacing can be more advantageous than uniform spacing. Hence an attempt is made here to study the influence of spacing of reinforcement on the behaviour of gabion faced reinforced soil walls and to arrive at an optimum value of spacing. For this, different configurations of reinforcement have been chosen as shown in Fig. 7.2. The configurations were fixed such that they are the stable configurations for a particular spacing.
The horizontal deformations of the facing for all the configurations were noted and plotted as shown in Fig. 7.3. Figure shows the variation of lateral deformation of gabion wall facing for the different models discussed above for $H = 6m$. The lateral deformation increases as the spacing of the basal reinforcement increases. In all the cases, it is seen that there is not much variation of lateral deformation in the embedded portion of the wall since the outward deformation is restricted by the foundation soil. The shape of the facing deformation changes from a linear form to a bow shaped form as the spacing of basal reinforcement of the reinforced gabion walls decreases and the maximum deformation is as low as 0.0036$H$. It is also seen that for medium to large spacings, say, $h/H = 0.25$ to 0.5, the deformation increases almost linearly with height from bottom to top and the maximum deformation at top is nearly 0.012$H$ for $h/H = 0.25$ and 0.04$H$ for $h/H = 0.5$.

In the case of unreinforced retaining wall, where the earth pressure increases towards bottom, the wall rotates about the base developing maximum deformation at the top. This rotation is restricted to a certain extent by the lateral ties in the reinforced cases. When closer spacing like $0.08H$ is used, the
strain is reduced to a very small value of 0.36%. Even if the spacing is reduced beyond a limit, there is not much difference in the reduction of lateral deformation as can be observed from the deformation plots for $h/H = 0.08$ and $h/H = 0.17$.

![Diagram showing facing deflection patterns for different reinforcement spacing configurations](image)

**Fig. 7.3 Facing deflection patterns for different reinforcement spacing configurations**

The behaviour of the gabion faced reinforced soil walls due to the variation in reinforcement spacing have also been analysed in terms of the lateral pressures developed. The variation of earth pressure for the different models were plotted (Fig. 7.4) for $H = 6m$. In the figure, the large dotted (green) lines represent Rankine's at-rest earth pressure distribution, the small dotted (blue) lines represent Rankine's active earth pressure distribution and the solid (red) lines represent the analytical results for the various models.
The horizontal dashed (black) lines indicate the location of basal reinforcement provided in the gabion boxes in each model.

![Graph showing lateral earth pressure (kPa) with spacing](image)

**Fig. 7.4 Variation of earth pressure with spacing**

The earth pressure distribution plots for the different cases analysed show a rise in lateral pressure when compared to the unreinforced case. At the location of reinforcements, a sudden rise of earth pressure can be noted in all the cases, which shows the stress concentration near the reinforcement.

A contradictory result compared to those published for flexible reinforced soil walls (Ogisako et al., 1988) is seen here. Instead of the reduction of earth pressure with decrease in spacing as reported in the literature, here the gabion faced walls being semi rigid walls, an increase in earth pressure is seen with the reduction of spacing. The reason for the same may be explained as follows.
To produce active condition of earth pressure, a retaining wall must rotate laterally away from the soil as per the deflection values listed in Table 7.2. For models (i) and (ii) with smaller spacing, the maximum deformation comes to around 0.004H indicating that the reinforced soil is near to the at rest condition. For medium spacings (models (iii) and (iv)), the maximum deformation is increasing to 0.012H - 0.015H, meaning that the system is in the verge of active condition and hence there is a decrease in the earth pressure values. For large spacing (model (v)), the maximum deformation is as high as 0.04H, clearly indicating an active state of earth pressure which is the minimum pressure the walls can withstand for stable equilibrium state. After this the structure fails which was clearly seen when the wall was analysed for unreinforced case. Here the maximum deflection was 0.06H which indicates an unstable state of earth pressure.

<table>
<thead>
<tr>
<th>Soil and condition</th>
<th>Maximum deflection values</th>
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<tbody>
<tr>
<td>Cohesionless, dense</td>
<td>0.001H to 0.002H</td>
</tr>
<tr>
<td>Cohesionless, loose</td>
<td>0.002H to 0.004H</td>
</tr>
<tr>
<td>Cohesive, firm</td>
<td>0.01H to 0.02H</td>
</tr>
<tr>
<td>Cohesive, soft</td>
<td>0.02 to 0.05H</td>
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In order to understand the variation of earth pressure with spacing, the earth pressure values for the different cases are to be compared. The total lateral force acting at the back face of the wall seems to be a better parameter for comparison than the lateral earth pressure. Hence for comparison purposes, lateral force was calculated from the earth pressure diagrams using the graphical method (plotting the earth pressure diagrams on graph paper and then calculating the lateral force as the area of the earth pressure diagrams which is obtained by counting the number of cells inscribed by the plots).

The rise in lateral earth pressure in the different cases due to the increase in the reinforcing effect is depicted in Fig. 7.5 (a). The plot was
prepared for $L/H = 1.00$ and $b/H = 0.15$. Here the decrease in earth pressure is calculated as:

$$\Delta P = \frac{(P_r - P_u)}{P_u} \times 100\% \quad \text{(7.1)}$$

where, $\Delta P$ is the percentage increase in lateral force of the reinforced cases when compared to that of the unreinforced case (where there is no reinforcement within the fill), $P_u$ is the total lateral force in the unreinforced case and $P_r$ is the total lateral force in the different models got from the FE analysis. The spacing ($h$) of the reinforcement is normalised using the wall height ($H$) and the ratio $h/H$ is taken as the abscissa.

The increase in earth pressure when compared to the unreinforced case is maximum for the heavily reinforced case and minimum for the case with minimum reinforcement. This is because, as spacing increases, the walls become unstable and the earth pressure becomes minimum as the system approaches the active condition. But the range of variation is very small unlike the hyperbolic variation exhibited by reinforced soil walls (Ogisako et al., 1988).

The reduction in deformation of reinforced gabion faced walls are plotted against the normalized spacing for the case $L/H = 1.00$. Here, the percentage reduction in deformation is defined as,
\[ \Delta u = \frac{(u_u - u_r)}{u_u} \times 100\% \]  

where \( u_u \) is the maximum lateral deformation in the unreinforced case and \( u_r \) is the maximum lateral deformation in the different reinforced cases. As expected, as the spacing becomes smaller the percentage reduction in deformation increases (Fig. 7.5 (b)).

The plots were prepared for three wall heights and the effect of variation of earth pressure is studied. For walls with low height, the percentage increase in earth pressure is lower when compared to the medium and high walls. It is also seen that as height increases, the percentage rise in earth pressure increases and the variation gradually becomes smaller.

The percentage reduction in deformation is seen to be smaller for low height walls and it increases as the height increases. The variation in percentage reduction in deformation between walls of 3m height and 6m (or 9m) height, is larger for smaller spacings and decreases gradually as spacing increases. The values become almost constant for walls of all heights at large spacings.

From the above discussions, it may be concluded that for any wall height, the ideal spacing of reinforcement may be fixed as, \( h = 0.1H \) to \( 0.2H \), as observed from Fig. 7.5 (b). 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.

### 7.4 EFFECT OF REINFORCEMENT LENGTH (L)

As per codal provisions, the length of reinforcement should be \( 0.7H \) for reinforced soil walls (BS 8006: 1995). To check the applicability of this provision on gabion faced reinforced soil walls, studies were conducted varying the lengths of reinforcement as \( 0.125H, 0.25H, 0.5H, 0.75H \) and \( 1.00H \).
Increase in lateral force (with respect to unreinforced case) due to the provision of reinforcement (with different lengths) in the different cases analysed, was plotted for $h/H = 0.08$ and $b/H = 0.15$ (Fig. 7.6 (a)). Here the length of reinforcement ($L$) is normalised using wall height ($H$) and is taken as the abscissa and percentage increase in lateral force as the ordinate.

![Graph showing effect of reinforcement length](image)

**Fig. 7.6 Effect of reinforcement length**

As the length of reinforcement increases, percentage increase in lateral force with respect to the unreinforced case increases. In other words, as the quantity of reinforcement increases, the earth pressure exerted on the back face of the wall increases, indicating the transformation of the state of earth pressure from below active condition to near to at-rest condition. i.e., the system changes from an unstable to a stable state which is clearly indicated by the reduction in deflection values with the increase in the quantity of reinforcement.

The variation in length was plotted against the change in deformations with respect to the unreinforced case (Fig. 7.6 (b)). Here also, as expected, as the length of reinforcement increases, the reduction in displacement increases. The variation in the reduction is just marginal for medium and high walls.
As the wall height increases, the percentage increase in lateral force increases, but the variation is very small. The percentage reduction in deformation is lower for low height walls and it increases gradually for walls of larger heights and the variation is nominal for medium and high walls. Moreover, observing from Fig. 7.6 (b), 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.

### 7.5 EFFECT OF FACING WIDTH (b)

In order to investigate the effect of the width of gabion facing on the behaviour of gabion faced reinforced soil walls, the same was varied keeping all the other parameters constant. Studies were conducted varying the widths of gabion facing as \(0.02H, 0.05H, 0.10H, 0.15H, 0.20H, 0.25H\) and \(0.30H\).

The effect of earth pressure on the increase in the width of gabion facing was plotted for \(h/H = 0.08\) and \(L/H = 1.00\). The facing width \((b)\) is normalised using wall height \((H)\). The normalised width of facing is taken as the abscissa, while the lateral force in kN exerted at the back face of the wall and the maximum lateral displacement of the facing in m are taken as the ordinates (Fig. 7.7).

It can be noted that as the facing width increases, there is not much variation in the lateral force exerted at the back face of the wall. This means that the facing rigidity has not much effect on the lateral force developed in the backfill. The variation in facing width has also been plotted against the maximum lateral deflection with respect to the unreinforced case (Fig. 7.7 b). Here it is seen that the increase in facing width decreases the maximum lateral displacement. For very thin facings, the displacements are seen to be maximum. For \(b/H \geq 0.1\), the displacement values are almost constant giving a linear horizontal shape to the latter part of the plot.
As the wall height increases, the lateral force and the displacement values also increase (Fig. 7.7). The variation in lateral force is nominal for medium and high walls. In the case of displacements, for thin facings, the variation in displacements with increase in wall height is seen to be large. For thicker facings, the corresponding variations are small. To summarise the study, the facing width may be fixed as 0.1H - 0.15H, beyond which the effect of deformations are seen to be marginal.

![Fig. 7.7 Effect of facing width](image)

7.6 SELECTION OF GEOMETRIC PARAMETERS

The present design method for the design of gabion faced reinforced soil walls is based on the assumption that the entire reinforced block acts as a rigid gravity structure and the deformations in the system are not taken into consideration. The design method of gabion faced reinforced soil walls, is a combination method based on the design of conventional gravity retaining structures and reinforced soil walls. As far as the gravity structures are concerned, the assumption may be true since the deformations in the structure are less because of its rigid nature. But the present design method is not a satisfactory method in the case of flexible reinforced soil walls and semi-rigid gabion faced walls, where, the deformations are a main issue. Hence the design method should be modified including the serviceability conditions.
An attempt is made here to prepare a general purpose design chart from which the length and spacing of reinforcement as well as the width of gabion facing can be selected for a maximum deformation of the wall. The design chart (Fig. 7.8) was prepared for maximum lateral deformation ($u_{\text{max}}$, on the X axis) in terms of the length of reinforcement ($L$, on the left Y axis) and width of facing ($b$, on the right Y axis) for different spacing of reinforcement ($h$), for a wall height of 6m. All the above parameters were normalised by dividing it by $H$ to make them non-dimensional.

The bold lines represent the curves for the selection of reinforcement length (to be read from left Y axis) and the dotted lines represent the plots for choosing the facing width (to be read from right Y axis). This chart is the standard chart prepared for $H = 6m$. For walls of any other height, the interpolation chart shown in Fig. 7.9 may be made use of. The chart was prepared from the results of corresponding FE studies conducted on 3m (low) and 9m (high) walls. The same trend as in Fig. 7.8 was obtained for 3m and 9m high walls also but the magnitudes were different. Hence an interpolation chart was prepared with the height of the wall as X axis and magnification factor as Y axis. The magnification factors for $L$ and $b$ ($[(L/H)_{\text{req}} H / (L/H)_{H=6m}]$ or $[(b/H)_{\text{req}} H / (b/H)_{H=6m}]$) for different heights were obtained by normalising $L$ and $b$ values with the corresponding values for a 6m wall. A logarithmic curve (Fig. 7.9) could be fitted between the points where the $R^2$ value was obtained as 0.9984 indicating a good fit. The curve was then extrapolated forwards up to 20m height and backwards up to 0.5m height. For selecting the geometric parameters for any wall height, the length and facing width should be obtained from Fig. 7.8 and those values should be multiplied by the magnification factor selected from Fig. 7.9.

This design chart can be used in the preliminary design of gabion faced soil retaining walls to select the length and spacing of reinforcement and the width of gabion facing in order to bring the deformations in the system to a minimum value. The method of using the charts is described in detail in Chapter 9.
Fig. 7.8 Design chart for selecting geometric parameters (H = 6m)

Fig. 7.9 Interpolation chart for selecting geometric parameters for any height

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7.7 EFFECT OF POSITION OF STRIP LOADING

Strip loads like pipelines, edges of bridge seating, cranes, compactors etc., are commonly seen at a retaining wall project site. These are permanent loadings and before the placement of these loads over the structure in the case of a gabion faced reinforced soil wall, the behaviour of the walls should be studied under the action of these loads.

For this, FE studies were conducted by applying strip load of same intensity (35kN/m which is the usual load taken for the design of bridges etc.), but of varying widths at various positions and maximum lateral deformation is noted. Strip width is denoted as $x_s$ and the position is denoted as $a_s$. $a_s$ denotes the distance of the start of strip load from back face of wall. These parameters are schematically represented in Fig. 7.10. The same FE mesh shown in Fig. 7.1 is used for this study also.

Strip was varied in position at different values of $a_s/L = 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75$ and $2.00$. The strip width was varied at values of $x_s/L = 0.10, 0.20, 0.30, 0.50, 0.75$ and $1.00$ for the parametric studies. The deformation in Fig. 7.11 is expressed in terms of percentage increase in deformation with respect to the case with no strip loading (self weight alone).

Fig. 7.11 shows the variation of top lateral deformation of the facing with change of strip position from back face of wall for different width of strip loading. As expected, the deformation increases with increase in width of strip loads. Regarding the strip position, the ratio $a_s/L = 0$, represents that the start of the strip loading is at the back face of the wall. From the figure, it is very clear that this is the most critical loading position as the percentage increase in deformation with respect to the unloaded case is maximum here. One more critical plane can be identified from the figure where all the curves show a peak. This is at $a_s/L = 1$, where the percentage increase in deformation is found to be more compared to other positions. The best position of strip loading can also be identified from Fig. 7.10 which is $a_s/L > 1.5$. Another suitable position range
may also be located from the figure as $a_s/L = 0.5$ to $0.75$. It is at these two positions where the percentage increase in deformation is lesser compared to other positions.

Fig. 7.10 Schematic representation of parameters of strip loading studies

Fig. 7.11 Effect of strip position on deformation
Thus 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. i.e., strip should be placed away from the reinforced region. If in any case, the strip has to be placed inside the reinforced area, the best position is the start of the strip loading should be within the range 0.5L – 0.75L from the back face of the wall.

The results of the FE studies performed here were replotted to develop a design chart (Fig. 7.12) from which the position of strip loading may be fixed by considering the deformation criteria. With the aid of this chart, knowing the limiting deformation and strip width, the ideal position of strip loading can be selected, which is described in detail in Chapter 9.

![Design chart for fixing strip loading position](image)
7.8 SUMMARY

Conventional design procedures of retaining walls in general, do not take into account wall deformation which is usually considered as a minor criterion in design. But in the present trend, even standard codes are being amended to accommodate the limit state design where serviceability conditions are also given equal importance, and hence a deformation study is resorted to.

FE analyses of gabion faced reinforced soil retaining walls were carried out for different reinforcement spacings, reinforcement lengths and facing widths on low (3m), medium (6m) and high (9m) walls. The relation between wall heights, spacing of reinforcement and length of reinforcement and the effect of the earth pressure acting on the wall and the facing deformation are discussed in detail in this chapter and optimum values have been suggested in each case. Moreover, the application of the analysis results in the design of the walls is also proposed. The effect of position of strip loading was also studied and recommendations are given to place the strip loading at a suitable position by minimising the deformations. The results from the geometric parametric studies as a whole are expected to aid the design engineers to fix the preliminary dimensions and thereby making the design process more comfortable.