A MODEL STUDY ON RETAINING WALL WITH REINFORCED BACKFILL

Iqraz Nabi Khan[1] and Swami Saran[2]

[1]*Professor & Head, Department of Civil Engineering, Sri Balaji College of Engineering and Technology, Benad Road, Jaipur-302013, Rajasthan, INDIA.*

[2]*Professor, Department of Civil Engineering, Indian Institute of Technology, Roorkee-247667, INDIA.*

Email: iqraz56@yahoo.co.in

ABSTRACT

The usefulness of the patented reinforced earth wall of Vidal, where reinforcement is attached with the skin panels, has been proved beyond doubt but under certain circumstances a conventional retaining wall with reinforced backfill may appear more appropriate. Keeping in view this fact, a model study has been conducted to observe the effect of reinforcing the backfill. Earth pressure on 1.0 m high model wall was monitored and pressure due to unreinforced backfill was compared to the pressure due to reinforced backfill. Different lengths of bamboo strips and geogrids were used for strengthening the backfill. Observations for the rotation of wall and corresponding base moment were recorded. These results were used to verify a theoretical analysis developed for inclined retaining wall having reinforced backfill with uniformly distributed surcharge load. The analysis was used to develop non-dimensional charts for designing retaining walls with reinforced backfill. The analysis was applicable for both strip and mat type reinforcements. Results indicated decrease in moments up to about 65 percent due to reinforcing the backfill. The observed moments were less than the corresponding theoretical moments. It may be due to side-wall friction of test tank which seems to have prevented the full development of failure wedge. There is no significant decrease in earth pressure where D_p value is greater than 1.0 and L/H value greater than 0.6.

Keywords: *Conventional Retaining Wall With Reinforced Backfill, Reinforced Earth, Unattached Reinforcement*

1. INTRODUCTION

The usefulness of the patented reinforced earth wall of Vidal has been proved beyond doubt by the thousands of such structures constructed all over the world, particularly in developed countries. Under certain circumstances a conventional retaining wall with reinforced backfill may appear more appropriate. The backfill reinforced with unattached strips / sheets / geogrids / geotextiles etc. laid horizontally may cause an appreciable decrease in the lateral thrust on the retaining wall which can be designed for the reduced sliding and overturning forces. There is less danger of strips breaking away due to differential settlement between the fill and the wall.

Though the concept of reinforcing soil to improve its strength is not new but efforts have been directed more to the study of Vidal's retaining wall than any other type of soil reinforcing technique. That is why there is very little literature available on retaining walls with reinforced backfill. Brooms, 1977, 1987 [1,2] analysed the internal and external stability of a retaining wall with attached and unattached continuous (or sheet) fabric reinforcement. The wall facing was made up of pre-cast L-shaped units and the reinforcement was laid horizontally in the backfill. Hausman and Lee, 1978 [3] have reported model tests on rigid wall with backfill reinforced with Mylar strips. The experiments were carried out with a 61 cm high and 76 cm wide rigid model wall designed to rotate about the knife-edge support at the bottom. Talwar, 1981 [4] developed theoretical analysis for computing earth pressure distribution, total pressure and its point of application behind a retaining wall with a vertical back and retaining cohesionless reinforced backfill. The investigator supported his theoretical findings with model test results. Experiments were conducted on a 46.5 cm high and 62.7 cm long rigid model retaining wall supporting reinforced backfill with no surcharge load. Garg, 1988 [5] extended the work of Talwar, 1981 [4] considering the uniformly distributed surcharge load on the backfill. He also developed a concept of economical placement of reinforcement. Theoretical findings were supported by laboratory model tests. Khan, 1991 [6] extended the work of Talwar, 1981 [4] and Garg, 1988 [5]. Khan, 1991 [6] produced non-dimensional design charts derived in terms of wall parameters, soil properties, and characteristics and distribution of reinforcement. These were developed by considering equilibrium of the forces and moment acting on a horizontal element of soil within a Coulomb wedge assumed to have formed under lateral thrust. Purpose of this model study was to verify theoretical analysis developed for designing inclined retaining wall having reinforced backfill with uniformly distributed surcharge load, which is briefly described in the following sections. Analysis of inclined retaining wall with reinforced backfill was not considered by Talwar, 1981 [4] and Garg, 1988 [5]..

2. EXPERIMENTAL INVESTIGATION

Model study was conducted on 1.0 m high model retaining wall. Details of the experimental investigation are presented in the subsequent sections.

2.1 Soil and Reinforcement

The soil used in this study was dry sand. The soil was classified as SP with effective size (D_{10}) of 0.185mm, coefficient of uniformity (C_u) of 1.30. Backfill soil was deposited at a density of 16.0 kN/m^3, relative density of 60 percent. Angle of internal friction, obtained from direct shear test, was 37°.

The reinforcements used were strips of bamboo and geogrids. Bamboo strips were recovered by stripping bamboo along its outer periphery and then cut to desired size. Average width of bamboo strips was 25 mm and average thickness 1.5 mm. The rupture strength was 12.75×10^4 kN/m^2. The lengths of reinforcement used for the study were 800 mm, 600 mm and 400 mm. Geogrid used for this study was commercially available geogrid, with mesh aperture size 8 mm × 6 mm, mesh thickness 3.3 mm and maximum load per unit length was 7.68 kN/m.

2.2 Test Set-Up

Model tests were performed in a tank of size 2250mm × 1000mm × 1250mm high. It was made of steel sections. One longitudinal side of the box was provided with perspex sheet properly stiffened to avoid any bulging. The purpose of the perspex sheet was to observe the rupture surface.

On one side of the tank, a rigid model retaining wall of 1000 mm height was provided. The wall was hinged at its knife-edge bottom to the tank base; such as it could rotate freely to and fro, without touching the tank sides. Nine holes were provided to accommodate earth pressure cells to measure horizontal pressure intensity along the depth of the retaining wall. Size of the tank behind the model wall was 1550 mm long, 870 mm wide and 1100 mm high. Height of fill was kept 1000 mm (equal to wall height). A circular plate with spherical seating for a steel ball was fixed centrally to the front of the wall at a height of 450 mm from base to make contact of wall with Proving Ring. The other end of proving ring was attached suitably to screw jack arrangement supported by an A-frame; it was further stiffened by providing two channels on both sides of it. Two screws at a height of 840 mm and clamps at top of wall were provided to keep the wall vertical during sand filling and application of surcharge load if any.

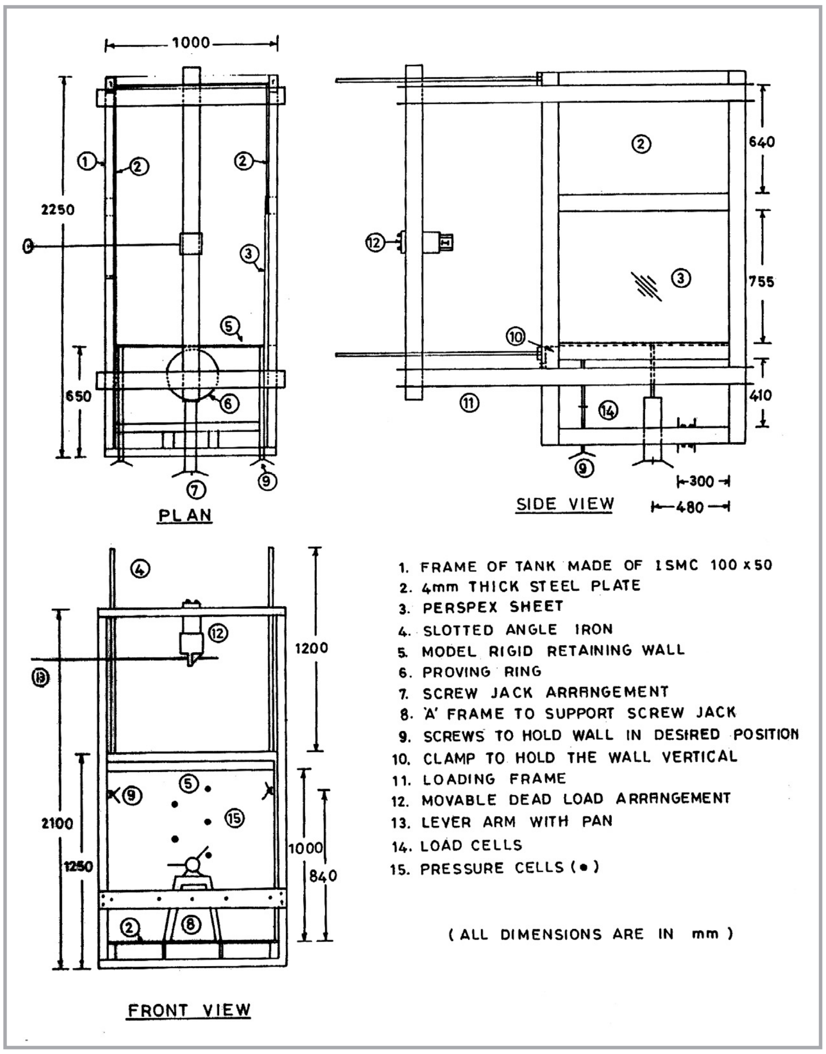

Figure 1: Model tank with loading facilities.

2.3 Positioning of Wall

The wall was clamped by two clamps after bringing it to perfect vertical position with the help of tri-square. Each clamp was fixed to the two top side channels with the help of nuts and bolts. Two screws marked 9 in Figure 1 were brought into contact of the wall and tightened. The wall was maintained in perfect vertical position by adjusting the screws provided with clamps. The purpose of these screws was not to allow even a slightest movement of the wall. There were narrow gaps between sides of tank and wall. Arrangements were made to prevent leakage of sand through the narrow gaps. The dial gauges were fixed in position and their initial readings were recorded.

2.4 Reinforced Backfill

After recording initial values of dial gauges, sand was placed in the tank by rainfall technique up to the predetermined level of first layer of reinforcement to give the desired density (16.0 kN/m^3). The sand was allowed to fall through holes of 3mm diameter spaced at 25.4 mm centre to centre. The height of fall 550mm and the lift 100mm were adopted for achieving density of 16.0 kN/m^3. The top surface of sand was levelled properly and the reinforcement was laid, it was laid at the specified horizontal spacing, if strips were used. It was laid perpendicular to the inner face of wall and just touching the face of wall. Coloured sand bands were made at every 100 mm fill height. Now sand filling was resumed over these coloured bands or reinforcement till the next locations of reinforcement or colour band arrived. In this way total reinforced backfill was achieved.

2.5 Measurement of Lateral Movement of Wall and Failure Surfaces

Three dial gauges fixed at different heights against outer face of wall were used to measure outward rotation of wall. The observation of dial gauges were used for computation of rotations of wall.

Breaks in coloured bands were observed through transparent Perspex sheet. The location of these break points with respect to the initial vertical position of wall was recorded and plotted on graph paper. Shape of failure surface is then obtained by joining these kinks.

2.6 Measurement of Overturning Moment

After achieving the reinforced backfill up to the top of the model wall, the two side-clamps holding the wall vertical, were removed. Now both the screws provided at 840 mm from bottom were unscrewed slowly to allow the wall to rotate slowly about the base and transfer the load to the proving ring placed with wall. The lateral force recorded through proving ring multiplied with the height of point of measurement of forces gives the overturning moment. Thus the rotation of wall and the corresponding overturning moment was recorded. Now very small rotations were given to the wall by rotating screw jack, dial gauge readings and corresponding overturning moments were recorded till active state was crossed. It was indicated by increase in overturning moment with increased rotation of wall.

2.7 Tests Performed

Seven tests were performed on the model retaining wall (active state) in the laboratory. One test was conducted without providing any reinforcement in the backfill. Three tests were conducted by reinforcing the backfill with bamboo strips.

Length of bamboo strip for test No. 2 was 800mm, test No. 3, 600 mm and test No. 4, 400 mm. Reinforcement was placed at a horizontal spacing S_H = 210 mm, vertical spacing S_V = 140mm, average width of reinforcement w = 22 mm, friction coefficient between bamboo strip and soil f^* = 0.675 [6] giving dimensionless factor D_p as 0.5. Where $D_p = wf^*H/(S_H S_V)$, and H = height of wall. Other three tests were conducted by reinforcing the backfill with geogrids. Length of geogrid for test No. 5 was 800 mm, test No. 6, 600 mm and test No. 7, 400 mm. Sheets of geogrid reinforcement were placed throughout the width of tank at vertical spacing S_V = 333.3 mm, friction coefficient between geogrid and soil f^* = 0.6128 [6] giving dimensionless factor D_p as 1.838. Where $D_p = f^*H/(S_V)$, and H = height of wall. The sand was deposited at a density of 16.0 kN/m^3.

2.8 Tests Results

Overturning moments, measured in the laboratory experiments, acting on the model retaining wall have been plotted against the rotation of the wall top expressed as percentage of height (H) of model wall. Figures 2 to 8 show the test results of test number 1 to 7 respectively. These figures also show the plots of traces of failure surfaces as measured on the side perspex sheet along the broken bands of coloured sand. Summary of test results is provided in Table 1.

Table 1: Summery of test results

Experiment No.	Moment (N-m)	Rotation of wall top (%H)	Wedge angle θ^o_w
1	244.0	1.14	16°
2	197.0	1.18	12°
3	175.0	1.06	8°
4	213.0	1.2	9°
5	141.0	0.85	10°
6	118.0	0.8	8°
7	138.0	1.15	10°

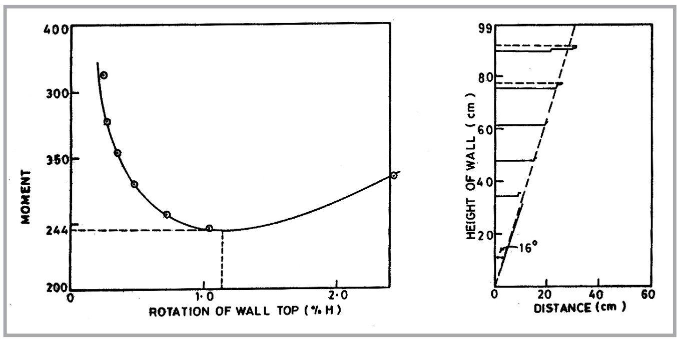

Figure 2: Observed overturning moments (N-m) v/s wall rotation and rupture surface (Exp. No. 1)

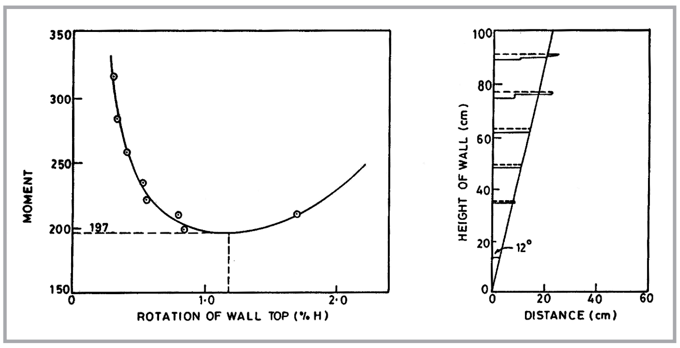

Figure 3: Observed overturning moments (N-m) v/s wall rotation and rupture surface (Exp. No. 2)

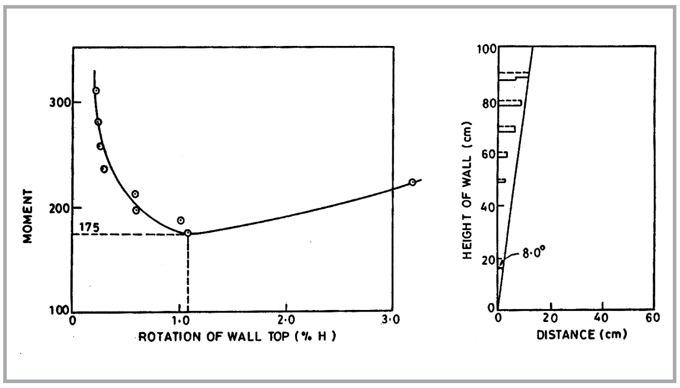

Figure 4: Observed overturning moments (N-m) v/s wall rotation and rupture surface (Exp. No. 3)

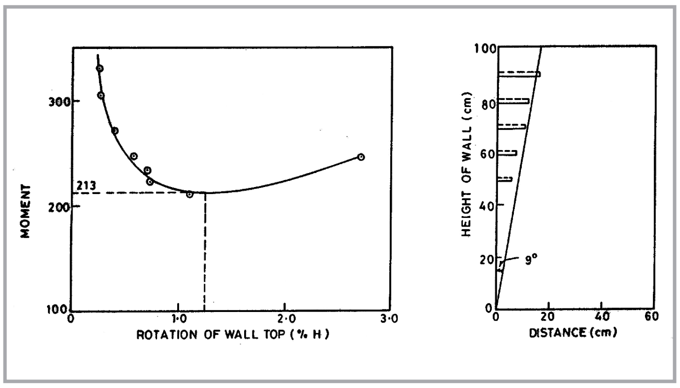

Figure 5: Observed overturning moments (N-m) v/s wall rotation and rupture surface (Exp. No. 4)

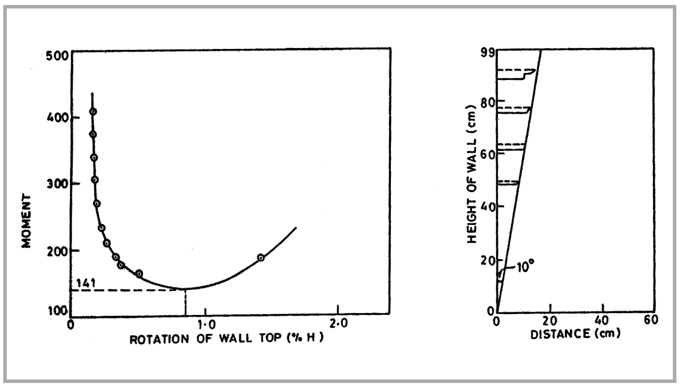

Figure 6: Observed overturning moments (N-m) v/s wall rotation and rupture surface (Exp. No. 5)

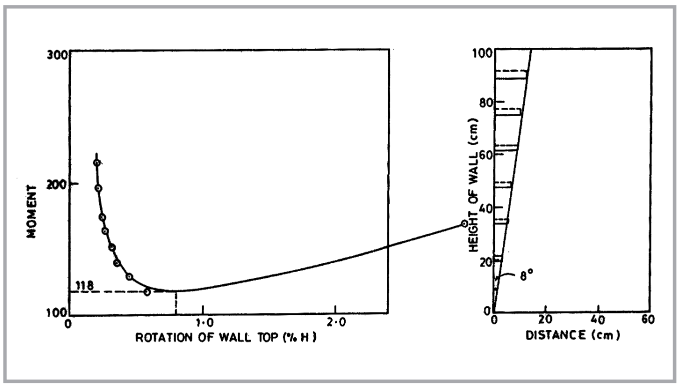

Figure 7: Observed overturning moments (N-m) v/s wall rotation and rupture surface (Exp. No. 6)

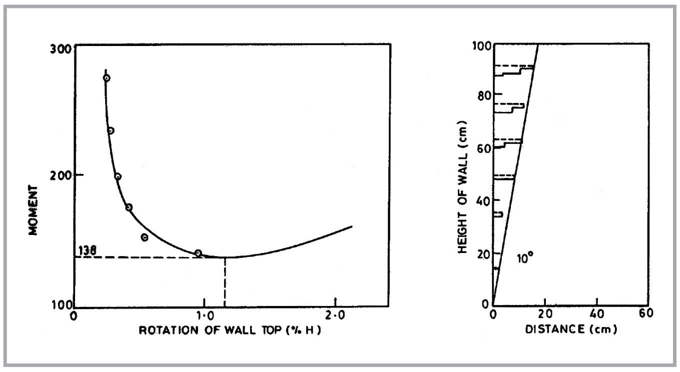

Figure 8: Observed overturning moments (N-m) v/s wall rotation and rupture surface (Exp. No. 7)

3. THEORETICAL ANALYSIS

Theoretical analysis has been developed for conventional retaining wall with inclined back retaining reinforced backfill supporting uniformly distributed load and being presented in the following sections.

3.1 Assumptions

Following were the assumptions made to develop the analysis of inclined retaining wall having reinforced backfill with uniformly distributed surcharge load.

1. The backfill is homogeneous, isotropic and non-cohesive.

2. The failure surface is a plane passing through the heel of retaining wall.

3. The coefficient of friction between soil and reinforcement is independent of the overburden pressure and length of reinforcement.

4. The failure plane divides the length of reinforcing strip in two zones, one that lies within failure wedge, another outside the failure wedge. Only that part of strip which experiences movement of soil relative to itself is assumed to be contributing frictional resistance.

5. The frictional resistance to the lateral movement of wedge of backfill behind the retaining wall contributed by a reinforcing strip is assumed to be uniformly distributed over a fill height equal to vertical spacing of reinforcement encompassing that reinforcement strip.

6. The retaining wall undergoes an outward movement or rotation about the base which is sufficient to cause mobilisation of full frictional resistance in the soil as well as reinforcing strips.

3.2 Analysis

Consider a retaining wall of height H with inclined back making angle β with vertical, retaining a horizontal cohesionless backfill of dry density γ and angle of internal friction ϕ supporting uniformly distributed load of intensity q (Figure 9). It is reinforced with unattached horizontally laid strips of length L and width w at vertical spacing S_V and horizontal spacing S_H. A failure plane BC making an angle θ with the vertical passes through the heel of retaining wall. The frictional resistance to the lateral movement of the wedge ABC contributed by reinforcing strip is computed from its effective length. Effective length is the portion of the strip which experiences movement of soil relative to itself. Reinforcing strips located within the moving wedge will not contribute any frictional resistance to the movement of wedge.

Considering equilibrium of an element IJKM of thickness dy of failure wedge ABC; located at a depth y from the top of the wedge (Figure 9). Following forces per unit length of the wall act on the element of the wedge ABC.

p_y :pressure intensity acting on IJ in the vertical direction

$(p_y + dp_y)$:pressure intensity acting on KM in the vertical direction

p_θ :reaction intensity on JK acting at an angle ϕ to the normal to JK

p :pressure intensity on IM acting at an angle δ with the normal to IM

W :weight of slice IJKM acting downwards

T :tensile force in the strip assumed transmitted uniformly to soil layer of thickness S_V encompassing the strip

$$T{:}t = \frac{T}{S_V} = \frac{2wf^*}{S_H S_V}$$

L_e :effective length of reinforcement, the portion of the strip which experiences movement of soil relative to itself.

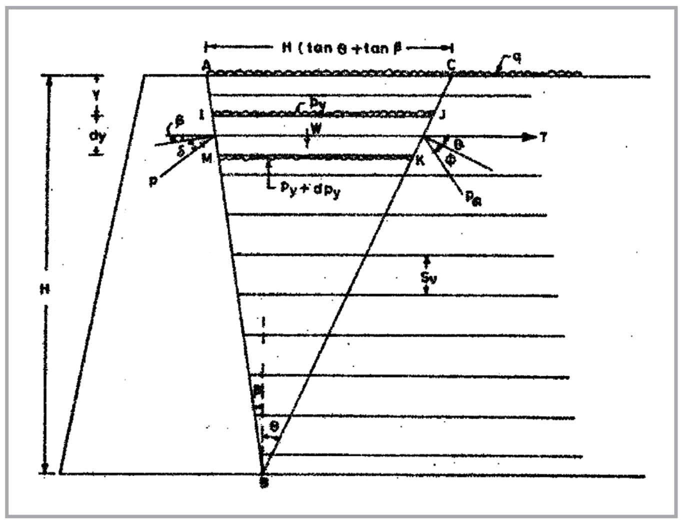

Figure 9: Wall details with reinforcement

(i) Considering static equilibrium of the element of wedge under the action of all the forces in horizontal direction and expressing in non-dimensional form:

$$p_\theta' = \frac{t' + p'\cos(\delta+\beta)\sec\beta}{\sec\theta\cos(\theta+\phi)} \tag{1}$$

where, $p_\theta' = \dfrac{p_\theta}{\gamma H}$, $t' = \dfrac{t}{\gamma H}$, $p' = \dfrac{p}{\gamma H}$.

(ii) Considering static equilibrium of the element of wedge under the action of all the forces in vertical direction, neglecting small quantities of second order and expressing in non-dimensional form:

$$\frac{dp'_y}{d'_y} = \frac{p'_y}{(1-y')} + 1 - \frac{p'}{(1-y')}\frac{\sin(\delta+\beta)\sec\beta}{(\tan\theta+\tan\beta)} - \frac{p'_\theta}{(1-y')}\frac{\sin(\theta+\phi)\sec\theta}{(\tan\theta+\tan\beta)} \tag{2}$$

where, $d'_y = \dfrac{d_y}{H}$ and $y' = \dfrac{y}{H}$.

(iii) Taking moments of all the forces about the mid point of slice between J and K. Neglecting small quantities of higher order, simplifying and expressing in non-dimensional form:

$$\frac{dp'_y}{d'_y} = 1 - \frac{2p'}{(1-y')}\,\frac{\sin(\delta+\beta)\sec\beta}{(\tan\theta+\tan\beta)} - \frac{2p'}{(1-y')}\left\{\frac{\tan\theta}{(\tan\theta+\tan\beta)} - 1\right\} \tag{3}$$

Solving equations 1, 2 and 3; we get:

$$p' = C_1 p'_y - C_1\,\frac{\tan(\theta+\phi)}{\tan\theta}\,t' \tag{4}$$

where,

$$C_1 = \frac{(\tan\theta - \tan\beta)}{\cos(\delta+\beta)\sec\beta\tan(\theta+\phi) - \sin(\delta+\beta)\sec\beta}$$

On differentiating Equation 4 and simplifying, we get:

$$\frac{dp'}{d_{y'}} = -C_2\,\frac{p'}{(1-y')} + C_1 - C_3\,\frac{dt'}{dy'} - C_4\,\frac{t'}{(1-y')} \tag{5}$$

where,

$$C_2 = \frac{2\{C_1\sin(\delta+\beta)\sec\beta - \tan\beta\}}{\tan\theta + \tan\beta},$$

$$C_3 = \frac{C_1\tan(\theta+\phi)}{\tan\theta - \tan\beta} \quad \text{and}$$

$$C_4 = \frac{2C_1\tan\beta\tan(\theta+\phi)}{\tan^2\theta - \tan^2\beta}$$

Neglecting C_4 being very small for small values of β, we get

$$\frac{dp'}{dy'} = -C_2\,\frac{p'}{(1-y')} + C_1 - C_3\,\frac{dt'}{dy'} - C_4\,\frac{t'}{(1-y')} \tag{5a}$$

At the limiting equilibrium, the value of t can be taken as:

$$t = \frac{2wf^*\sigma_v L_e}{S_H S_V}$$

where,

w = width of reinforcing strip,
f^* = apparent coefficient of friction between backfill soil and reinforcement,
σ_v = vertical stress on strip,
L_e = effective length of strip.

The value of L_e will vary from strip to strip and will depend on wedge angle θ and length L of strip. There may be three cases as shown in Figure 10. Case 1 when $H(\tan\theta+\tan\beta) \le L/2$, case 2 when $L/2 \le H(\tan\theta+\tan\beta) \le L$ and case 3 when $H(\tan\theta+\tan\beta) \ge L$. It can be seen from the Figure 10 that if Le > 0, the effective length is equal to either (H-y-dy/2) $(\tan\theta+\tan\beta)$ or L-(H-y-dy/2) $(\tan\theta+\tan\beta)$.

Equation for pressure distribution along the height of wall may be obtained by solving differential Equation 5a:

$$\frac{p'}{(1-y')^{C_2}} = \left[\int C_1(1-y')^{-C_2} - \int C_3(1-y')^{-C_2}\,\frac{dt'}{dy'}\right] dy' \tag{6}$$

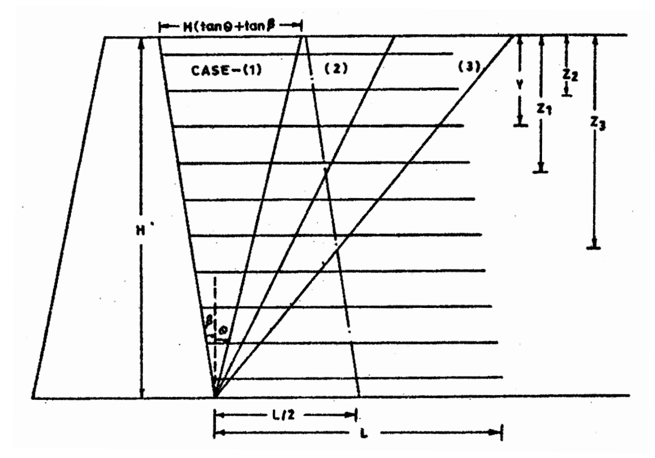

Figure 10: Schematic representation of three cases of analysis

$$\text{or}\quad \frac{p'}{(1-y')^{C_2}} = I_1 - I_2 + K \tag{7}$$

where

K = coefficient of integration,

$$I_1 = \frac{-C_1(1-y')^{1-C_2}}{(1-C_2)}$$

$$I_2 = \frac{-C_3}{(1-C_2)}\left[\frac{dt'}{dy'}\,(1-y')^{1-C_2} + \frac{d^2t'}{dy'^2}\,\frac{(1-y')^{2-C_2}}{(2-C_2)}\right]$$

Equation 7 was solved for all the three cases to obtain pressure intensity on the wall. While solving Equation 7 a non dimensional factor D_p was introduced. Where D_p = (wf*H)/($S_H S_V$). Detailed theoretical analysis is given elsewhere [6]. The value of the total pressure was obtained by numerical integration neglecting the negative pressure. The pressure intensities become negative in some of the portion of the wall. The design of wall needs to check its stability against sliding and overturning. The former needs the value of maximum resultant earth pressure which is obtained by optimising it with respect to wedge angle θ. Similarly the moments of the positive pressure intensities were taken about the heel of the wall and the same is optimised with respect to wedge angle θ to obtain its maximum value. The optimised values of resultant earth pressure and moments are denoted by P and M respectively and are presented in the charts in non-dimensional form as $P\Big/\frac{1}{2}\gamma H^2$ and $M\Big/\frac{1}{2}\gamma H^2$ respectively. Figure 11 shows such non-dimensional chart for Resultant Earth Pressure versus L/H (Stability against Sliding) for $\phi = 35^o$, $\beta = 0^o$ and 10^o and q/γH = 0.0, 0.5 and 1.0, Figure 12 shows non dimensional chart for Resultant Moment versus L/H and Resultant Earth Pressure versus L/H (Stability against Overturning) for $\phi = 35^o$, $\beta = 0^o$ and q/γH = 0.0, 0.5 and 1.0. Figure 13 shows non dimensional chart for Resultant Moment versus L/H and Resultant Pressure versus L/H (Stability Against Overturning) for inclined retaining wall having $\phi = 35^o$, $\beta = 10^o$ and q/γH = 0.0, 0.5 and 1.0

4.0 INTERPRETATIONS OF RESULTS AND DISCUSSIONS

4.1 Justification of Assumptions for Theoretical Analysis

Assumptions 1, 4 and 6, reported earlier, are normally made is such analysis. The anisotropy caused by inclusion of reinforcement, has been considered in indirect way by taking the frictional strength of strip in the direction of reinforcement. Assumptions 2, 3 and 5 are being justified in the following paragraphs.

It is a well-established fact that the error in resultant pressure due to the assumption of planer surface in active condition is very small (less than 5 percent).

The work of earlier investigators [4, 5, 8, 9, 10] indicate that the apparent coefficient of friction between soil and reinforcement decreases with increase in the length of reinforcement and decreases with increase in overburden pressure. However, the findings include that this trend was observed for low range of overburden pressure and for smaller lengths of reinforcement. Khan and Saran, 2005 [10] reported that the value of apparent coefficient of friction did not vary with overburden pressure greater that 100 kN/m^2 and length of reinforcement more than 3.0 m.

In case of retaining walls higher than seven meters, for which reinforced backfill will provide an economical solution, taking average range of height of overburden and length of reinforcement will fall in a range for which the apparent coefficient of friction f^* is fairly constant. Keeping above fact in view, the assumption 3 was made.

Model tests have been performed for different vertical spacings. The test data compares well with the predicted values from the proposed theory. From this it may be said that if the spacing between the reinforcement assumed is reasonable then the assumption of uniform distribution of frictional resistance imparted by reinforcement over a fill height equal to its vertical spacing, may be considered valid.

4.2 Results and Discussion

Figures 2 to 8 show a steep fall in the moments in the beginning with more gradual decrease with increasing rotation. The minimum value of moment, in most of the tests corresponding to active condition, was reached at rotations around 1 to 1.2 percent *H*. The experimental overturning moments, reported in Table 1 is much less than their corresponding theoretical values. It may be due to the sliding friction developed between the sand and the two sides of test tank. Therefore the magnitudes of moments of friction forces, acting on the two sides of tank (adjoining model wall) have been calculated theoretically with the help of following Equation (8).

$$M_F = \frac{1}{12}\left[K_{OR}\gamma H^4 \tan\theta(\tan\delta_s + \tan\delta_p)\right] \qquad (8)$$

where,

M_F = Moment, about base, of side frictional forces,
K_{OR} = $K_O(M_{T2}/M_{T1})$,
K_O = Coefficient of earth pressure at rest = 1- sin ϕ
M_{T1} = Theoretical moment due to unreinforced backfill without surcharge,
M_{T2} = Theoretical moment due to unreinforced/ reinforced backfill with surcharge,
δ_s = Angle of wall friction between sand and mild steel side wall of tank,
δ_p = Angle of wall friction between sand and perspex sheet forming side wall of tank.

Derivation of this equation has been provided by Khan 1991 [6]. The moment of side frictional forces on both sidewalls have been computed using Equation 8 for observed wedge angle. This moment has been added to measured experimental moment and has been reported as observed moment in Table 2.

Figures 11, 12 and 13 show the effect of reinforcement in backfill in reducing the earth pressure on inclined retaining wall with reinforced backfill. The earth pressure decreases rapidly with increase in L/H value from 0 to 0.6 and D_p value from 0 to 1.0. These figures also indicate that there is no significant decrease in earth pressure for higher values of D_p and L/H ratio. It indicates that the design may become uneconomical due to higher quantities of reinforcement provided in the backfill and may be of no use. The charts are in non-dimensional form based on the analysis developed. These charts should be useful for all practical ranges of retaining wall heights. The theoretical findings are supported by conducting model study on 1.0m high model wall only. Tests may be conducted on prototype retaining walls and/or bigger models to verify the theoretical findings.

Table 2: Comparision of observed and theoretical moments

Experi-ment no	L/H	Observed moment (N-m)	Theoretical moment (Nm)	% Reduction in observed earth pressure due to reinforced backfill
1	0.0	400.0	559.8	Unreinforced
2	0.8	234.8	184.1	41.3
3	0.6	201.6	195.1	49.6
4	0.4	271.4	380.6	32.1
5	0.8	155.2	83.0	61.2
6	0.6	138.9	152.9	65.3
7	0.4	189.2	298.9	52.7

The experimental study indicates slightly less moments when L/H ratio was 0.6 as compared to observed moments for L/H ratio 0.8 for both reinforcements. However the difference is about 10 percent. It may be contributed to size effects and/or experimental errors. Still it needs further investigations.

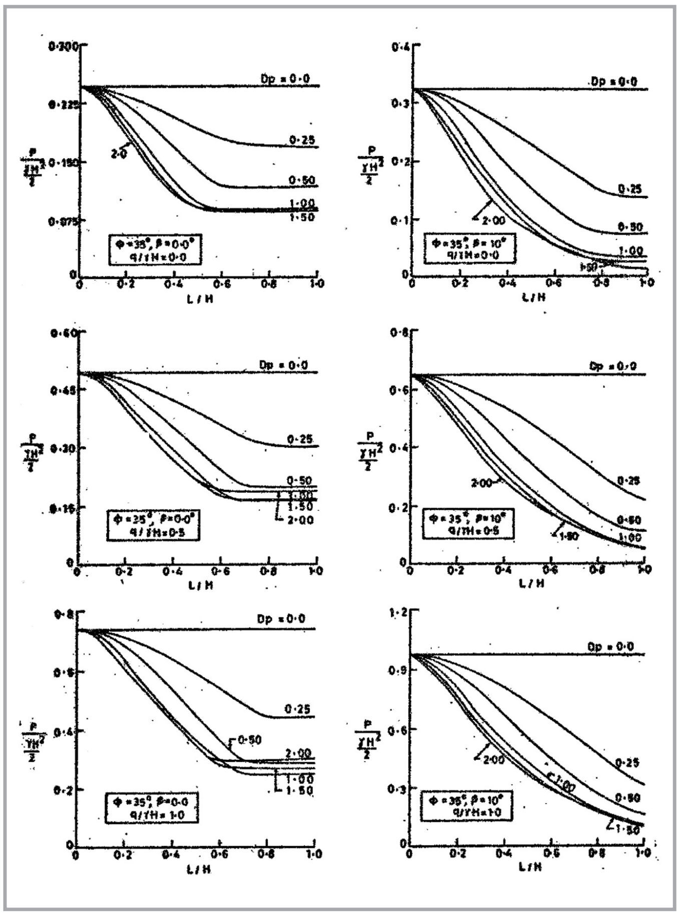

Figure 11: Resultant earth pressure versus L/H (Stability against sliding)

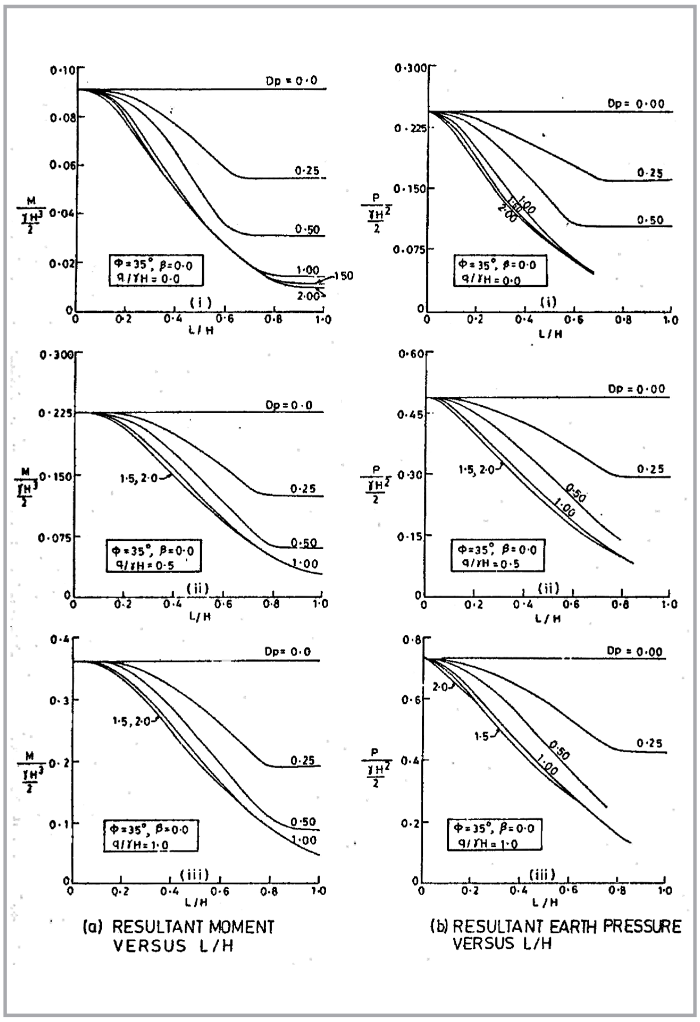

Figure 12(a): Resultant moment versus L/H and (b) resultant earth pressure versus L/H (Stability against overtutning)

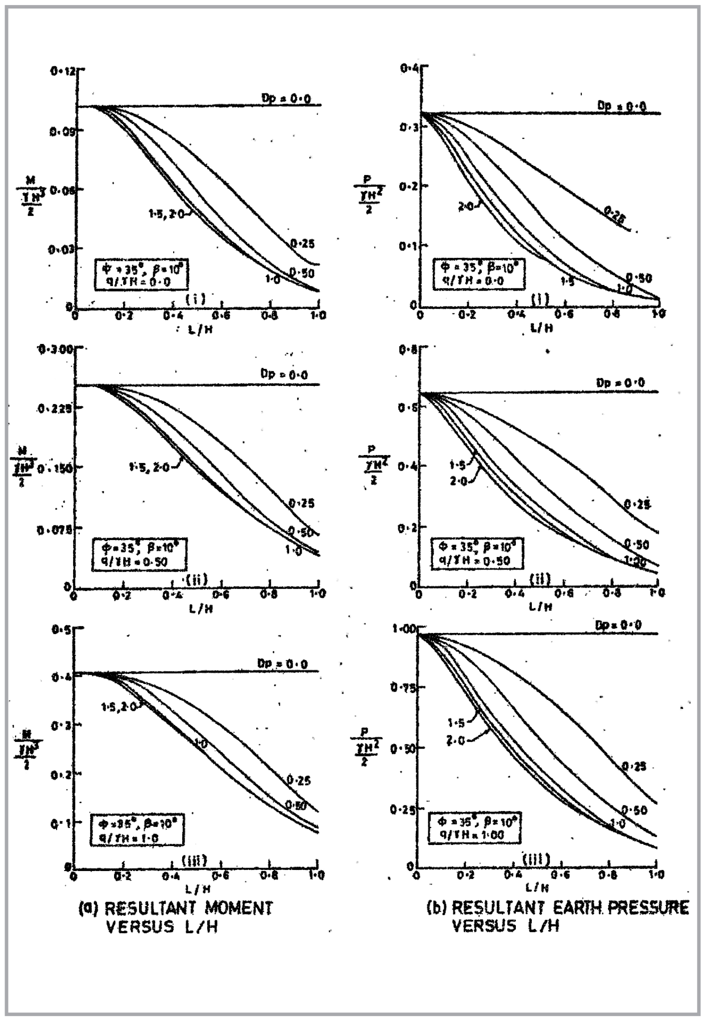

Figure 13(a): Resultant moment versus L/H (b) resultant earth pressure versus L/H (Stability against overturning)

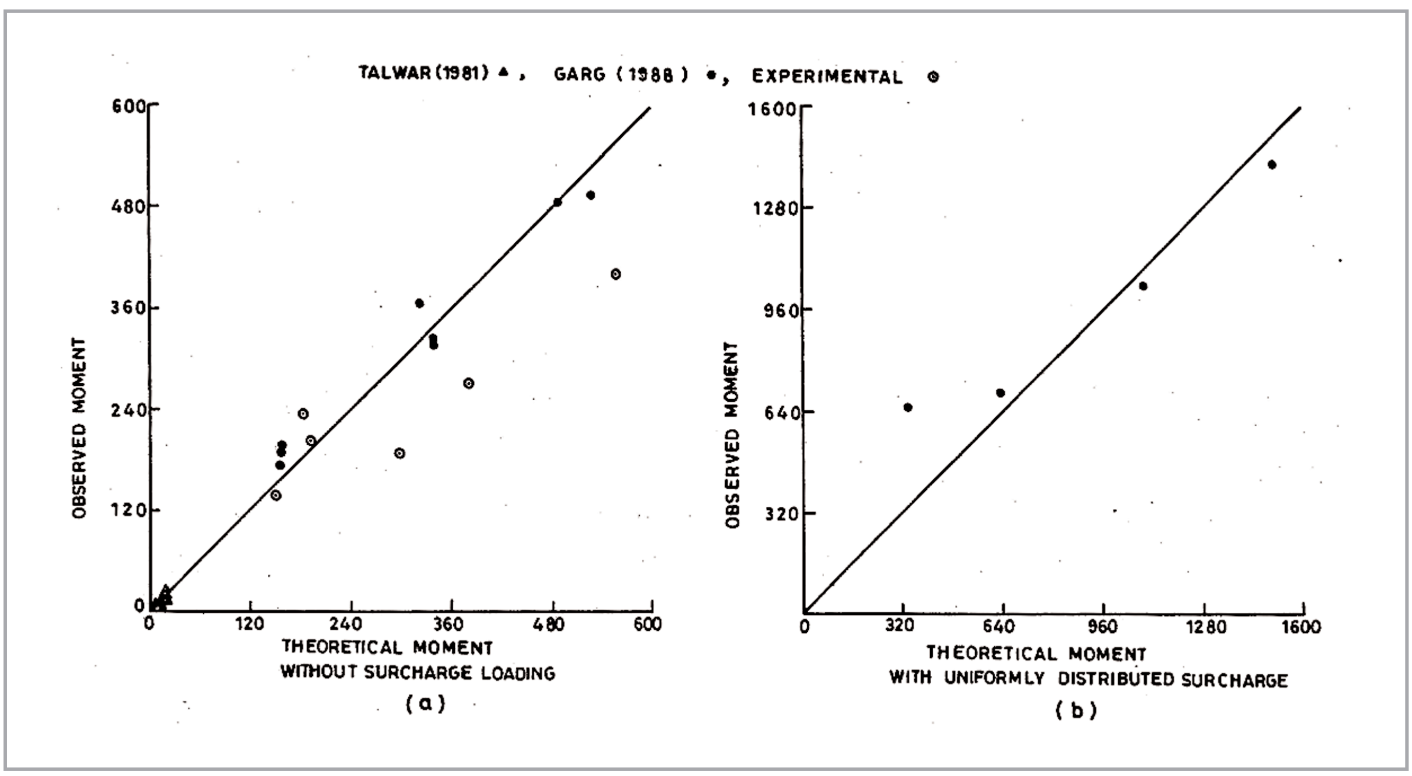

Figure 14: Comparison between theoretical and observed moments

Figure 14 shows comparison between the theoretical and observed moments from present study [4], [5]. There is good correlation between the theoretical and observed moments. Garg, 1998 [11] reported a case study of retaining wall with reinforced backfill, which shows usefulness of the technique.

6.0 CONCLUSIONS

The paper reports the findings of the experimental model study and the analytical analysis carried out for conventional retaining wall with inclined back retaining reinforced backfill with uniformly distributed surcharge. Following conclusions may be drawn from the theoretical and experimental findings reported in the paper:

i) Unattached reinforcing strips considerably reduce the lateral pressure intensity on the wall.

ii) Experimental findings reveal that the reduction is about 50 percent in case of bamboo strip reinforced backfill (D_p = 0.5) and 65 percent in case of geogrid reinforced backfill (D_p = 1.838) having L/H = 0.6. So the value of L/H = 0.6 gives the minimum value of observed overturning moment.

iii) This finding confirms the recommendations based on theoretical analysis that the value of L/H = 0.6 can be adopted for economical design of retaining wall with reinforced backfill.

iv) There is no significant decrease in earth pressure where D_p value is greater than 1.0.

ACKNOWLEDGEMENT

Thanks to Mrs Clotilda Petrus, Mrs. Goh Lyn Dee and Mrs Caroline Peter, Universiti Teknologi MARA, Malaysia for proof readings and Mr. Ramesh Chandra, Sri Balaji College of Engineering and Technology, Jaipur, Rajasthan (India) for his help in editing. ■

REFERENCES

[1] Broms, B.B., "*Polyester Fabric as Reinforcement in Soils*". Proc. International Conference on the Use of Fabric in Geotechnics, Paris, France, Vol. 1, pp. 129- 135, 1977.

[2] Broms, B.B., "*Fabric Reinforced Soils*". Proc. International Symposium on Geosynthetics, Geotextiles and Geomembranes, Koyoto, Japan, pp 13-54, 1987.

[3] Hausmann, M.R. and Lee, K.L., "*Rigid Model Wall With Soil Reinforcement*". Proc. Symposium on Earth Reinforcement, ASCE, Pittcburg, pp. 400- 427, 1978.

[4] Talwar, D.V., "*Behaviour of Reinforced Earth in Retaining Structures and Shallow Foundation*", Ph.D Theses, Department of Civil Engineering , University of Roorkee, Roorkee, India, 1981.

[5] Garg, K.G., "*Earth Pressure Behind Retaining Wall With Reinforced Backfill*", Ph.D. Thesis, Department of Civil Engineering, University of Roorkee, Roorkee, India, 1988.

[6] Khan, I.N., "*A Study of Reinforced Earth Wall and Retaining Wall With Reinforced Backfill*", Ph.D. Thesis, Department of Civil Engineering, University of Roorkee, Roorkee, India, 1991.

[7] Khan,I.N. and Saran, S. (2004). "*Flood Prevention Wall With Reinforced Backfill*". Proc. of Seminar on Water Management for Sustainable Environment, August 25-26, 2004, UiTM, Shah Alam, Malaysia.

[8] Bacot, J.; Itlis, M.; Lareal, P.; Paumier, T. and Sanglert, G.. "*Study of The Soil Reinforcement Friction Coefficient*". Proc. Symposium on Earth Reinforcement, ASCE, Pittsburg, pp. 157-185, 1978.

[9] Schlosser, F. and Elius, V.. "*Friction in Reinforced Earth*". Symposium on Earth Reinforcement, ASCE, Pittsburg, pp.735-763, 1978.

[10] Khan, I.N. and Saran, S.. "*A Study of The Phenomenon of Soil –Reinforcement Interaction*", Journal Institution of Engineers, Malaysia, Vol. 66, No. 2, June 2005, pp 38-45, 2005.

[11] Garg, K.G.. "*Retaining Wall With Reinforced Backfill- A Case Study*", J. Geotextiles and Geomembranes, Elsevier, Vol. 16, pp. 135-149, 1998.

PROFILES

Prof. Iqraz Nabi Khan
Professor & Head,
Department of Civil Engineering,
Sri Balaji College of Engineering and Technology,
Benad Road, Jaipur-302013,
Rajasthan, India.

Prof. Swami Saran
Professor
Department of Civil Engineering,
Indian Institute of Technology,
Roorkee-247667, India.