www.hsd.ait.ac.th/bestprac/earthqua.htm

Sicherheit : 1,5 !

$\mu = \tan \rho = 0.6 \div 0{,}7 = \theta$

Das griechische Alphabet

Α	α	Alpha	Ν	ν	Ny
Β	β	Beta	Ξ	ξ	Xi
Γ	γ	Gamma	Ο	ο	Omikron
Δ	δ	Delta	Π	π	Pi
Ε	ε	Epsilon	Ρ	ρ	Rho
Ζ	ζ	Zeta	Σ	σ	Sigma
Η	η	Eta	Τ	τ	Tau
Θ	θ	Theta	Υ	υ	Ypsilon
Ι	ι	Jota	Φ	φ	Phi
Κ	κ	Kappa	Χ	χ	Chi
Λ	λ	Lambda	Ψ	ψ	Psi
Μ	μ	My	Ω	ω	Omega

48-6

Paper No. 356

"RETAINING WALL FOR HILL ROADS" †

By

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CONTENTS

† Written comments on this Paper are invited and will be received upto 30th November, 1983.

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SYNOPSIS

This Paper lays emphasis on the construction of random rubble dry stone masonry retaining walls for any height on the basis of strength analysis, design criteria and behaviour of such existing retaining walls on various hill roads where such retaining walls even more than 10 m height are seen standing well since a long time back. The main reason of the damages to most retaining walls on hill roads is ineffective drainage during the monsoon. The various common causes for failure of hill road retaining walls, the necessary precautions during construction, and suggestions for adopting wall sections in various rock zones are described herein. Special precast bonding elements are suggested for dry masonry walls of large height. It is shown that much economy can be achieved in the construction of hill roads by adopting the suggestions advanced in this Paper in place of some of the current practices.

1. INTRODUCTION

The hill road retaining walls are constructed on valley side of hill roads to add the required road width where cost of hill cutting may become higher than the cost of building retaining walls. In the present practice in various road departments, retaining walls upto 4 m height are constructed in random rubble dry stone masonry. Those of above 4 m height are built either in lime or cement mortar masonry or in dry stone masonry provided with 0.6 m wide mortarred masonry bands at 3 to 4 m apart laid in both the horizontal and vertical directions.[1,2] These specifications are provided irrespective of the nature and the properties of soil or rock below the wall base and at the back of the wall, or the weather conditions. Sometimes, wooden mesh is formed in which dry stone masonry is built. This is known as Crib wall. These specifications seem to be rather the rules of thumb'. The reason for providing fully mortarred masonry or bands or crib masonry according to published works are to give strength to the wall for added stability and to confine local failure, if any. Observed behaviour of various types of walls, however, shows that a number of dry as well as banded or fully mortarred retaining walls do collapse during rains without showing much difference in resistance. Thus fully mortarred or banded masonry does not appear to be of much help during an emergency. It is also observed that a large number of random rubble dry stone masonry retaining walls of height even more than 10 m height have been standing well for many years on many roads, Photos 1 to 4. The aim of this Paper is to examine in depth the resistance and behaviour of dry stone masonry retaining walls and to show that they are indeed safe structures and may result in large economy if adopted for all heights of retaining walls commonly required on hill roads.

2. DESIGN CRITERIA FOR RETAINING WALLS

Hill road masonry retaining walls are gravity walls whose stability depends upon their weight. A gravity wall is safe if following stability criteria are fulfilled.

(a) There should be no overturning of the wall as a whole or any part of it. According to IS : 1904, the minimum factor of safety against overturning is specified as 2.0 under normal loads. Under earthquake condition as per IS : 1893 – 1975, the factor of safety should be 1.5. or more.

(b) The pressure at the toe should remain less than the safe bearing capacity of foundation soil or rock. The factor of safety with respect to ultimate bearing capacity is kept as 3.0 under normal loads. Under earthquake condition, the allowable bearing pressure may be increased by 25 to 50 per cent (IS : 1893).

(c) The sliding or shearing stress should remain less than the safe value of the shear or sliding resistance. A factor of safety of 1.75 under normal loads and 1.33 under earthquake condition is generally adopted, both at base and for intermediate layers.

For retaining walls, the lateral earth pressure and seepage water pressure, where present, are normal loads.

3. COMPARISON OF STRENGTHS OF DRY, BANDED AND FULLY MORTARRED MASONRY WALLS

It is quite obvious that according to the above criteria the strength of a dry stone masonry wall and a banded masonry wall or fully mortarred masonry wall should be equal when having same dimensions and similar soil conditions since both the walls are not supposed to bear any tension and the stability will depend on the compressive strength of foundation soil particularly under the toe and not on the compressive strength of masonry which will usually be quite adequate. For sliding at the base, the strength of both types of walls should not be different because it depends on the co-efficient of friction between the wall base and the foundation soil which are same in both types of wall. It should naturally be expected that the sliding strength even though dry stone masonry would be more that that at the base in view of the fact that the co-efficient of friction between stone and stone in dry masonry should be more than the co-efficient of friction between stone masonry and soil or rock at foundation level. Moreover, the total earth pressure above any level along the height of the wall reduces parabolically from base upwards whereas the wall thickness reduces linearly, Fig. 1. Therefore in most cases the critical section in the wall is at the base or at section AA in Fig. 1, and the sections at higher levels do not need any higher strength. The above discussion shows that there is no particular utility of bands or mortar strength of masonry as per specified design criteria and that the dry masonry wall should be quite sufficient to meet them adequately.

The above discussion pre-supposes, however, that the dry wall has been so carefully constructed that there is adequate frictional bond between the stone layers from face to back and from base to the top so that sections of the wall act integrally as one unit. This will be achieved if stones of roughly rectangular shape are used with sufficient overlap on each other for interlocking of the stones. The value of the bands or mortar is only from this integrity point of view, which also remains doubtful at most hill road sites due to lack of supervision and inadequate supply of water for mixing of mortar and curing after construction. It will be better to use some more positive means of achieving the bonding between the stones, as discussed in Section 11.

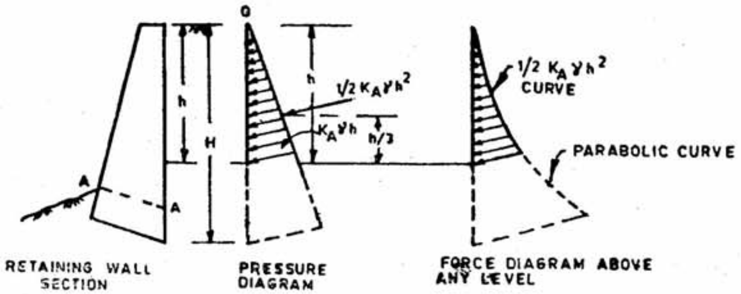


Fig. 1. Pressure Distribution on Retaining Wall

4. DETERMINATION OF SLIDING STRENGTH OF DRY STONE MASONRY RETAINING WALLS

The sliding strength of dry retaining walls will depend upon the frictional resistance acting between stone and stone or between the stone base and the rock or soil below base of the wall. Two cases may arise, first the contact may be on a horizontal plane or on an inclined plane. Then depending on the slope, the sliding movement may occur in upward or downward direction. Three cases are considered here as shown in Fig. 2.

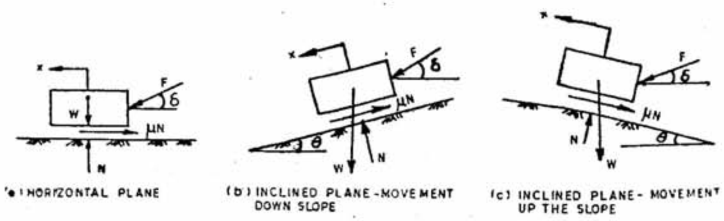


Fig. 2. Sliding Mechanism

Considering the limiting equilibrium in each of the three cases when the stone is on the point of movement along X-direction as shown in Fig. 2, the value of the applied force F required to cause movement should be as follows :

(a) Horizontal Plane (Fig. 2a)

$$F \geqslant \frac{\mu W}{\cos \delta - \mu \sin \delta} \quad ..(1)$$

(b) Inclined Plane - Movement down the Slope (Fig. 2b)

$$F \geqslant \frac{\mu \cos \theta - \sin \theta}{\cos (\delta - \theta) - \mu \sin (\delta - \theta)} W \quad ..(2)$$

(c) Inclined Plane - Movement up the slope (Fig. 2c)

$$F \geqslant \frac{\mu \cos \theta + \sin \theta}{\cos (\delta + \theta) - \mu \sin (\delta + \theta)} W \quad ..(3)$$

To understand the implications of these equations in terms of the dry retaining walls, let us consider a retaining wall as shown in Fig. 3 in which the earth face CF is kept vertical. The earth pressure acting on it will be inclined at an angle

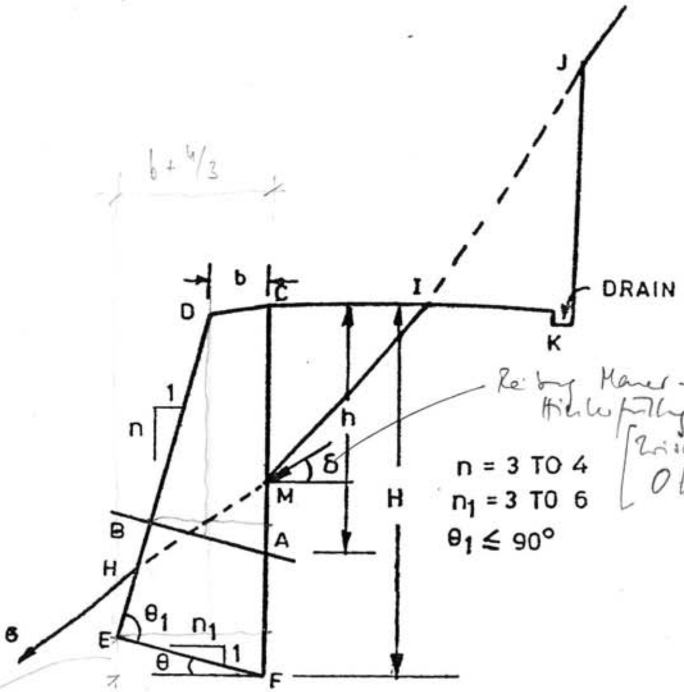


Fig. 3. Geometry of Retaining Wall

δ according to Coulomb's earth pressure theory where δ is the angle of wall friction. For sliding of the wall at the base, the condition shown in Fig. 2c will apply here wherein W will be the weight of wall and F the active earth pressure. For sliding to occur F will have to be according to Eq. (3) given above.

If in the body of the wall also, the bedding planes are kept parallel to the base, similar conditions will hold. But if the courses were laid horizontally, Eq. (1) will apply instead of (3). To get a feel of the numerical values, let $\delta = 20°$, $\mu = 0.7$. For $\theta = 15°$ from Eq. (3).

$$F \geqslant \frac{0.7 \times \cos 15° + \sin 15°}{\cos (20° + 15°) - 0.7 \times \sin (20° + 15°)} W$$

$$\geqslant 2.23 \; W \qquad ..(4)$$

For $\theta = 0°$, from Eq. (1)

$$F \geqslant \frac{0.7 \times W}{\cos 20° - 0.7 \times \sin 20°}$$

$$\geqslant 1.05 \; W \qquad ..(5)$$

This simple illustration shows the importance of keeping the bedding planes appropriately tilted to get greater strength or resistance.

For estimating the sliding force F in practical cases, consider a retaining wall as shown in Fig. 3, having b as top width 1 in 3 face slope, and vertical back. Using the unit weight of masonry as γ, it can be shown that the weight of masonry in CABD portion of the wall per unit length will be given by

$$W = \gamma \left[h \left(b + \frac{h}{6}\right) - \tfrac{1}{2} \left(b + \frac{h}{3}\right)^2 \frac{\tan \theta}{1 + \frac{1}{3} \tan \theta} \right] \qquad ..(6)$$

Using $b = 600$ mm, $\theta = 0°$ and $15°$, $\gamma = 1.8$ t/m^3, face slope as 3 : 1, the weight W as obtained from Eq. (6) and F from Eq. (3) will be as shown in Table 1.

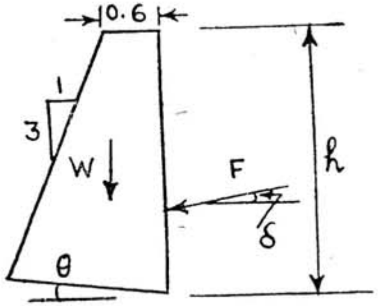
5. BACK PRESSURES ACTING ON HILL ROAD RETAINING WALLS

The lateral pressure acting on retaining wall depends on the angle of internal friction, density and water saturation of the fill material at the back of the wall. In hill regions, the fill material automatically depends on the nature of material obtained in hill cutting. Mainly six nomenclatures of rocks are used in classifying hill zones depending on their hardness to cutting: (1) Conglomerate rocks; (2) Homogeneous rocks; (3) Very hard rocks, shales; (4) Hard rocks, shales; (5) Medium soft rocks, shales; and (6) Earth or earth and boulders.

Nomenclatures 1 to 5 refer to hard material which is by itself quite stable. Such rocks may also remain stable in many

TABLE 1. WEIGHT OF WALL AND MINIMUM FORCE REQUIRED FOR SLIDING

Heigh h m	Weight per m length of Wall W t/m for, $\theta = 0$	$\theta = \tan^{-1}(\frac{1}{8})$	$\theta = \tan^{-1}(\frac{1}{3})$	Value of μ	Minimum Force for Sliding, Ratio F/W, for $\delta = 22.5°$: $\theta = 0$	$\theta = \tan^{-1}(\frac{1}{8})$	$\theta = \tan^{-1}(\frac{1}{3})$
3	5.94	5.58	5.25	0.6	0.864	1.425	2.444
4	9.12	8.59	8.11	0.75	1.778	2.003	3.892
5	12.90	12.17	11.51				
6	17.28	16.32	15.45				
7	22.25	21.04	19.94				
8	27.83	26.32	24.96				
9	34.02	32.18	30.52				
10	40.78	38.60	36.62				



Note : 1. Unit weight of masonry γ_m is taken here as 1.8 t/m^3. For any other value of γ_m weight may be obtained in the ratio of $\gamma_m/1.8$.

cases even in overhanging position. They will also provide stable hard foundation for the retaining walls. Nomenclatures 3, 4 and 5 may cause lateral forces if they are badly fractured and have dips or fractured plane inclined outwards and more so, if one or more boulders bounded by fracture joints are liable to slide away after construction of walls. It will be difficult to estimate the lateral pressures in such a case, but conservatively it may be assumed that such fills shall behave like rock fills.

Earth or earth and boulder fills of nomenclature 6 will cause little to appreciable pressure depending on site conditions and saturation with water. Let *GHMIJ* in Fig. 4 be a hill face which has been stable for ages in all states of rains and earthquakes. For construction of the road, hill mass *JIK* has been removed by cutting and material filled behind the

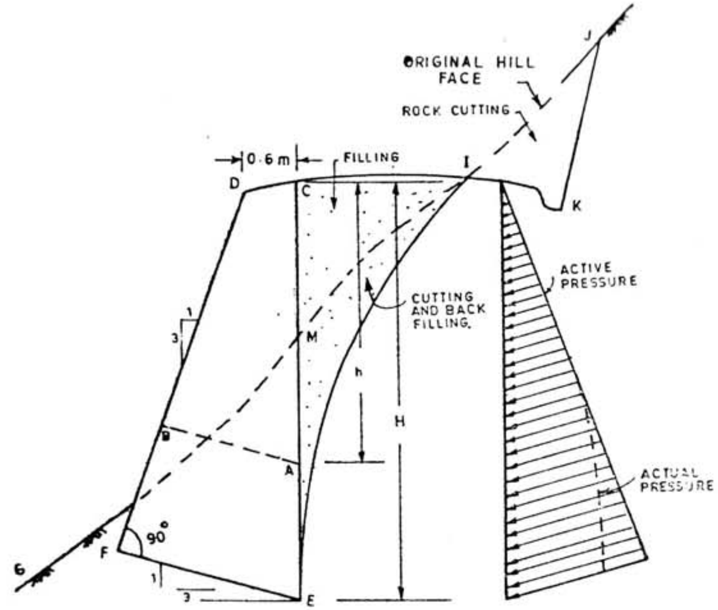


Fig. 4. Rock Cutting and Filling

retaining wall portion *EMCI*. After removal of surcharge weight *JIK* and adding weight of fill and the retaining wall the stability of slope below *HG* will be hardly affected. For design purpose of the wall, it may be assumed that there shall be soil pressure due to the mass of hill cutting filled in space *EMCI* and that of the water ingressing in this material from road surface drainage. It can easily be visualized that whereas the earth pressure is likely to be small, the hydrostatic water pressure could be very large and damaging to the wall if not designed for it. On the other hand, if the water could be drained off quickly no such problem will arise.

In computing the lateral pressures due to backfills, it is rational to use Coulomb's theory using suitable values of angle of internal friction of soil and angle of wall friction between the soil or rock fill and the back of the wall. Representative values of internal friction of soil are given in Table 2.[8]

TABLE 2. VALUES OF ANGLE OF INTERNAL FRICTION

Grain Size	State of Compaction	Value of Ø (degrees) Rounded Grains, Uniform Gradation	Value of Ø (degrees) Angular Grains Well Graded
Sand and Gravel	Loose	34	39
	Moderately Dense	37	41
Blasted rock fragments	as blasted	-	40 - 50

For rocky sites, where the fill will consist of blasted rock fragments it will be reasonably conservative to assume $\varnothing = 45°$. For hand-packed rock fills, the stability of fill will be much more by itself and Ø could even be higher than 50°. For earthen masses or boulders mixed in earthen matrix, a good conservative idea of the angle of internal friction could be obtained by observing the angle of repose at site, *i.e.*, the general angle of the hill slope Only in very silty situations, the angle Ø will do, down to the order of 30°. Also for unstable earth or earth and boulder zones where heavy slip comes after road cutting, angle of internal friction may be taken as 30° or the actual hill face slope whichever is lesser for design purposes. At any place if clay or expansive soil is met, its cohesion, drainage condition, and angle of internal friction should be determined by field or laboratory tests; otherwise there shall be no surety for stability of any retaining wall in this zone unless very heavy section is provided.

It may also be mentioned that rarely the fill behind the retaining wall will extend enough behind it wherein the complete Coulomb's wedge at an angle of more than $(45° + \varnothing/2)$ from the horizontal plane could be formed. The horizontal distance from wall to the wedge intersecting the road level is given in Table 3 for various wall heights and angles of internal friction. Unless such a situation exists, full active pressure will not be mobilised behind the wall.

The angle of wall friction δ in case of hill retaining walls which will be rough on their back will approach the angle of internal friction itself. Its values for relatively smoother

TABLE 3. EXTENT OF SOIL WEDGE

Height of Wall m	Horizontal extent of wedge at top b in m, for internal angle of friction 30°	35°	40°	45°	50°
4	2.31	2.08	1.87	1.66	1.46
6	3.46	3.12	2.80	2.49	2.18
8	4.62	4.16	3.73	3.31	2.91
10	5.77	5.21	4.66	4.14	3.64

Note: 1. For extent of fill b_1 equal to or more than $0.9b$ consider full Coulomb pressure on wall.

2. If b_1 is less than $0.9b$, the total pressure on the wall may approximately be reduced to a value in the ratio $b_1/0.9b$.

surfaces as in concrete walls or well foundations is kept limited to 22.5° It will be conservative to use $\delta = 22.5°$ even in the best surfaces of walls where coursed rubble construction is adopted using lime or cement mortars. For dry stone masonry an angle 27 - 30° should be nearer to reality.

6. SEISMIC FORCES

The active earth pressures acting on retaining walls are enhanced due to earthquake motions. The extent of this increase is called dynamic increment and can be computed by Mononobe-Okabe formula given in IS : 1893 - 1975 as follows :

The total active earth pressure including the earthquake effect is given by

$$P_a = 1/2\, \gamma\, h^2\, C_a \quad \ldots(7)$$

$$C_a = \frac{(1 \pm \alpha_v)\cos^2(\varnothing - \lambda - \alpha)}{\cos\lambda \cos^2\alpha \cos(\delta + \alpha + \lambda)} \times \frac{1}{\left[1 + \sqrt{\left\{\dfrac{\sin(\varnothing + \delta)\,\sin(\varnothing - i - \lambda)}{\cos(\alpha - i)\,\cos(\delta + \alpha + \lambda)}\right\}}\right]^2} \quad \ldots(8)$$

where

P_a = total earth pressure acting on the portion of wall upto depth h below ground.

γ = density of retained soil.

h = depth of portion of wall below ground.

C_a = co-efficient of active earth pressure.

α_v = vertical seismic co-efficient which may be taken equal to $\alpha_h/2$.

α_h = horizontal seismic co-efficient, values to be taken as per seismic zone from IS : 1893 - 1975.

$\varnothing$ = angle of internal friction of soil.

$= \tan^{-1} \dfrac{\alpha_h}{1 \pm \alpha_v}$

α = angle which the earth face of the wall makes with vertical.

i = slope of earthfill above the horizontal.

δ = angle of friction between wall and earth or stone fill.

In the above expression, the positive sign of α_v means a direction of vertical acceleration which increases the weight of soil wedge below and negative value will indicate decrease in its weight. The seismic co-efficients α_h and α_v should also be used on the mass of the wall in similar directions as shown in Fig. 5.

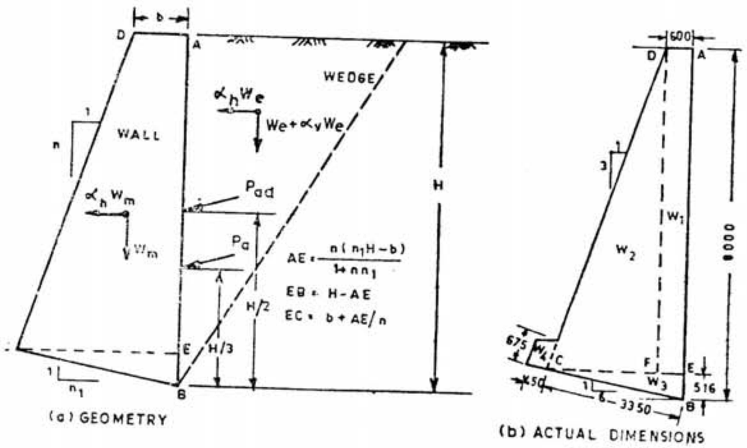


Fig. 5. Seismic Force on Retaining Wall

The point of application of the earth pressure on the retaining wall is calculated by splitting the total pressure calculated by Eq. (8) in two parts P_{as} and P_{ad} where P_{as} is the static component without earthquake and P_{ad} is the dynamic increment due to earthquake. To determine P_{as}, Eq. (8) may be used but by putting $\alpha_h = \alpha_v = \lambda = 0$. That is,

$$P_{as} = \tfrac{1}{2}\gamma h^2 \frac{\cos^2(\varnothing + \alpha)}{\cos^2\alpha \cos(\delta + \alpha)} \left[\frac{1}{1 + \left\{\dfrac{\sin(\varnothing + \delta)\sin(\varnothing - i)}{\cos(\alpha + i)\cos(\delta + \alpha)}\right\}^{1/2}}\right] \quad ..(10)$$

Then,

$$P_{ad} = P_a - P_{as}$$

The points of application of P_{as} and P_{ad} are to be taken at $h/3$ and $h/2$ respectively above the foot of the Coulomb wedge considered.

In the case of hill retaining walls, simplifications can be introduced by taking $\alpha = 0$, $i = 0$. Thus,

$$P_a = \tfrac{1}{2}\gamma h^2 \frac{(1 \pm \alpha_v)\cos^2(\varnothing - \lambda)}{\cos\lambda \cos(\delta + \lambda)} \left[\frac{1}{1 + \left\{\dfrac{\sin(\varnothing + \delta)\sin(\varnothing - \lambda)}{\cos(\delta + \lambda)}\right\}^{1/2}}\right] \quad ..(12)$$

and

$$P_{as} = \tfrac{1}{2}\gamma h^2 \frac{\cos^2\varnothing}{\cos\delta} \left[\frac{1}{1 + \left\{\dfrac{\sin(\varnothing + \delta)\sin\varnothing}{\cos\delta}\right\}^{1/2}}\right] \quad ..(13)$$

It may be clarified that both P_a and P_{as} act at an angle of δ with the horizontal and their horizontal and vertical components acting on the earth face of the wall shall be obtained by multiplying with $\cos\delta$ and $\sin\delta$ respectively.

The values of C_a for various values of $\varnothing$ and α_h are presented in Table 4 for ready reference and use; α_V is taken equal to $1/2\alpha_h$ and $\delta = 22.5°$. Value of C_a for $\alpha_h = 0$ are indeed for static case without earthquake. The use of the tabular values

TABLE 4. CO-EFFICIENT OF STATIC AND DYNAMIC EARTH PERSSURE

α_h	*Angle* $\varnothing$ *degrees*	*Value of Co-efficient* C_a *for* $i = 0°$	$i = 5°$	$i = 10°$	$i = 15°$
0	30	0.2973	0.3169	0.3421	0.3753
Static	35	0.2445	0.2587	0.2766	0.2995
Case	40	0.1992	0.2093	0.2219	0.2375
	45	0.1597	0.1668	0.1754	0.1861
	50	0.1253	0.1301	0.1360	0.1432
.04	30	0.3285	0.3521	0.3286	0.4242
Seismic	35	0.2720	0.2891	0.3109	0.3391
Zone III	40	0.2232	0.2355	0.2507	0.2699
	45	0.1806	0.1892	0.1998	0.2130
	50	0.1434	0.1493	0.1565	0.1655
.05	30	0.3365	0.3612	0.3933	0.4373
Seismic	35	0.2791	0.2970	0.3198	0.3496
Zone IV	40	0.2294	0.2422	0.2582	0.2785
	45	0.1860	0.1950	0.2061	0.2200
	50	0.1480	0.1543	0.1619	0.1713
.08	30	0.3613	0.3895	0.4267	0.4790
Seismic	35	0.3009	0.3214	0.3477	0.3825
Zone V	40	0.2485	0.2631	0.2815	0.3050
	45	0.2026	0.2129	0.2258	0.2419
	50	0.1624	0.1696	0.1785	0.1895

Remarks :
1. Value of angle of wall friction δ is taken as 20° for $\varnothing = 30°$ & 22.5° for $\varnothing \geqslant 35°$.
2. Seismic zones and co-efficients are as specified in IS : 1893 - 1975.
3. Pressure intensity at any depth h is $C_a \gamma_h$ and total force $= \frac{1}{2} C_a \gamma h^2$
4. The earth pressure will be inclined at δ to normal to the back of wall.

is explained by the following example :

Example

Given $H = 8$ m, $\varnothing = 40°$, $\delta = 22.5°$, $\mu = 0.6$, $\alpha_h = 0.08$, $\gamma_e = 1.8$ t/m^3 and $\gamma_m = 2.0$ t/m^3 to design a masonry retaining wall section when the bearing capacity of the rock under normal loads is 15 t/m^2.

As per Table 5, the retaining wall section is adopted as having top width b equal to 0.6 m, face slope 1 horizontal to 3 vertical, base slope 6 horizontal to 1 vertical and the toe projection as 0.45 m wide and 0.675 m high as shown in Fig. 5 (b). For $\varnothing = 40°$, $\delta = 22.5°$ and $\alpha_h = 0.08$, from Table 4.

TABLE 5. RECOMMENDED FACE SLOPES AND TOE PROJECTION

Angle $\varnothing$ *degrees*	*Height H m*		*Face Slope*	*Toe Projection Width mm*	*Toe Projection Thickness mm*	*Remarks*
1	2		3	4	5	6
30	upto	4	3 : 1	300	450	1. The toe projections recommended herein apply to the
		6	3 : 1	600	900	following erodible base conditions :
		8	3 : 1	800	1,200	
		10	3 : 1	1,200	1,800	a) Soil, b) Soil boulder mixture,
35	Upto	6	3 : 1	300	450	c) Soft rock, d)
		8	3 : 1	600	900	Soft friable rock,
		10	3 : 1	800	1,200	e) Soft Shales.
40	upto	6	3 : 1	300	450	2. For non-erodible rock bases, toe projection need not be provided.
		10	3 : 1	600	900	
45	upto	6	4 : 1	300	450	3. For intermediate heights, suitably chosen interme-
		10	3 : 1	300	450	diate values of width and thickness may be adopted.

(*Contd.*)

TABLE 5 (*Contd.*)

1	2	3	4	5	6
50	upto 6	4 : 1	300	450	4. For $\varnothing \geqslant 45°$, the face slope for upper 6 m shall be 4 : 1 and for lower part upto 10 m shall be 3 : 1 for high walls more than 6 m.
	10	3 : 1	300	450	

$C_a = 0.1992, \; C_{as} = 0.2485$

Static earth pressure :

$P_a = \frac{1}{2} \gamma_e C_a H^2 = \frac{1}{2} \times 1.8 \times 0.1992 \times 8^2$

$= 11.50 \; t$ acting at 2.667 m above base.

Total seismic earth pressure :

$P_{as} = \frac{1}{2} \times 1.8 \times 0.2485 \times 8^2 = 14.26 \; t$

Dynamic increment :

$P_{ad} = P_{as} - P_a = 14.26 - 11.50$

$= 2.76 \; t$ acting at 4.00 m above base.

Both the pressures P_a and P_{ad} will be inclined at angle 22.5° to the horizontal, where cos 22.5° = 0.9239 and sin 22.5° = 0.3827.

From the expressions shown in Fig. 5(a), the various dimensions of the present retaining wall shown in Fig. 5 (b) will be as follows :

$$AE = \frac{n(n_1 H - b)}{1 + n n_1} = \frac{3(6 \times 8 - 0.6)}{1 + 3 \times 6} = 7.484 \text{ m}$$

$$EB = H - AE = 8.0 - 7.484 = 0.516 \text{ m}$$

$$EC = b + AE/n = 0.60 + 7.484/3 = 3.095 \text{ m}$$

The computations of force components and their moments about B are given in Table 6.

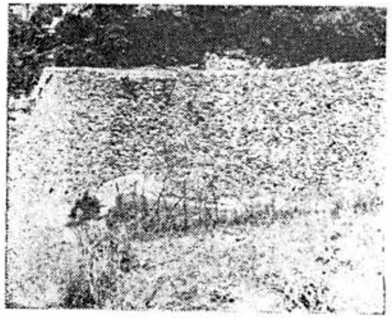


PHOTO 1. 7 m high dry stone masonry retaining wall, with side pedestrian-way of the same masonry

PHOTO 2. 9 m high dry stone masonry retaining wall in fractured very hard rock zone

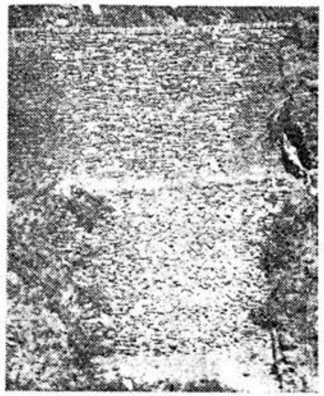


PHOTO 3. 10 m high dry stone masonry retaining wall in hard shale zone

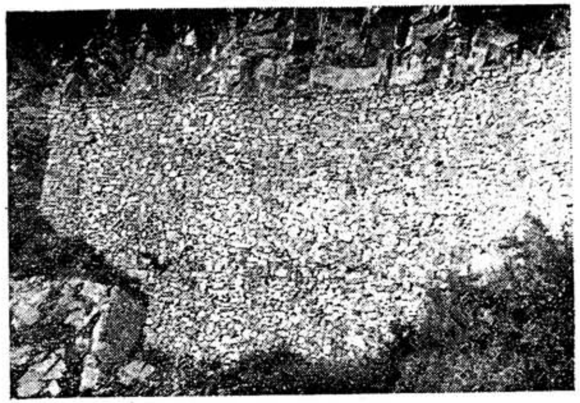


PHOTO 4a. 8.5 m high dry stone masonry retaining wall in fractured very hard rock zone with 2.5 m high toe wall, projecting out by 0.3 m. It is visible in photo below dry stone Kharanja

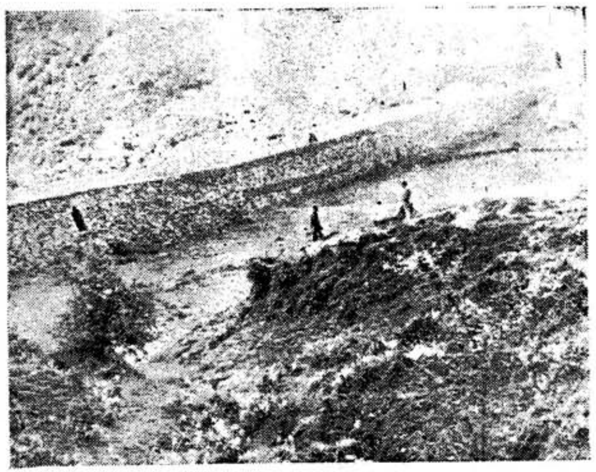


PHOTO 4b. About 150 m long 6 to 7.5 m high dry stone masonry retaining wall, Road completely in filling, no necessity of expansion joints in dry stone masonry retaining walls

PHOTO 5. Collapsed retaining wall due to splitting away of stones near face. All stretchers are placed along length. Masonry behind face stones shows random dumping.

PHOTO 6. 7 m high dry stone masonry retaining wall with two Scupper openings at 3 m apart for cross drainage. Similar openings have also been provided for relieving seepage water pressures.

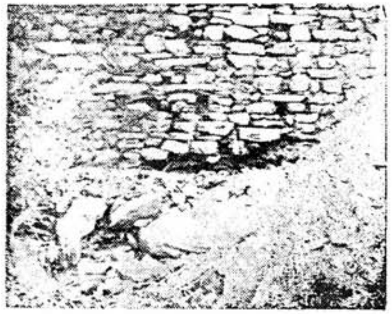


PHOTO 7. Erosion of soil and rock near toe of a 7.5 m high retaining wall. Wall has not fully collapsed due to arching action among interlocked stones of masonry

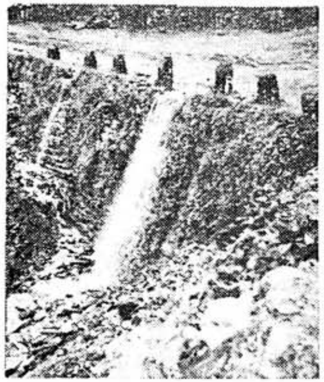


PHOTO 8. Toe wall at bottom dissipates the energy of falling rain water and avoids toe erosion

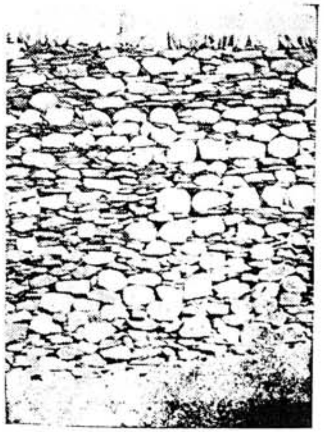


PHOTO 9. 7 m high dry stone masonry retaining wall constructed with egg-shaped boulders

TABLE 6. RETAINING WALL CALCULATIONS - MOMENTS ABOUT HEEL
(Horizontal force to left + ve : anti-clockwise moment + ve)

Force	Calculation	*Horizontal Component*			*Vertical component*		
		Force *t*	*L.A.* *m*	*M* *m*	*Force* *t*	*L.A.* *m*	*M* *tm*
P_a	11.50 x .9239	10.60	2.667	28.27	-	-	-
	11.50 x .3827	-	-	-	4.40	0	0
W_1	0.6 x 7.484 x 2.0	-	-	-	8.98	0.300	2.69
W_2	0.5(3.095 - 0.6) x 7.484 x 2.0	-	-	-	18.67	1.432	27.64
W_3	0.5 x 3.095 x 0.516 x 2.0	-	-	-	1.60	1.032	1.65
W_4	0.4 x 0.675 x 2.0	-	-	-	0.61	3.320	2.02
	Sub Total	10.60	-	28.27	34.26		33.10
P_{a1}	2.76 x .9239	2.55	4.00	10.20	-	-	-
	2.76 x .3827	-	-	-	1.06	0	0
EQ1	0.08 x 8.98	0.72	4.258	3.06	-	-	-
EQ2	0.08 x 18.67	1.49	3.011	4.50	-	-	-
EQ3	0.08 x 1.60	0.13	0.322	0.04	-	-	-
EQ4	0.08 x 0.61	0.05	0.854	0.04	-	-	-
	Total	15.54	-	46.11	35.32		33.10

Check for Sliding

Here the sliding movement will be 'up the slope' as in Fig. 2(c). Hence the force required to cause sliding is governed by Eq. (3), as given in Table 1, that is, 1.425 times the vertical weight.

Without earthquake, Vertical load = 34.26 t

Force required to slide = 1.425 x 34.26 = 48.82 t

Actual sliding force = 10.60 t > 48.82 t OK

With earthquake, Vertical load = 35.32 t

Force required to slide = 1.425 x 35.32 = 50.33 t

Actual sliding force = 15.54 t > 50.33 t OK

Stresses at Base

a) Without Earthquake

Total moment about $B = 28.27 + 33.10 = 61.37 tm$.

Resultant load normal to base

$= 34.26 \cos 9.462° + 10.6 \sin 9.462°$

$= 35.54 \ t$

Inclined base width $= 3.095 \sec 9.462° + 0.45$

$= 3.800$ m

Distance of resultant from $B = \frac{61.37}{35.54} = 1.727$ m

$e = 1.727 - 3.80/2 = -0.173$ m, that is, towards B.

$$p = \frac{35.54}{3.800}\left(1 \pm \frac{0.173 \times 6}{3.800}\right) = 11.91, .798 \ t/m^2 < 15t/m^2$$

OK

b) With Earthquake

Total moment about $B = 46.11 + 33.10$

79.21 t m

Resultant load normal to base

$= 35.32 \cos 9.462° + 15.54 \sin 9.462°$

$= 37.39$ t

Distance of resultant from $B = \frac{79.21}{37.39} = 2.118$ m

$e = 2.118 - 1.900 = 0.218$ m

$$p = \frac{37.39}{8.800}\left((1 \pm \frac{.218 \times 6}{3.800}\right) = 13.23, 6.45 \ t/m^2$$

Allowable bearing pressure under earthquake condition will be 25 per cent more according to Table 1 of IS : 1893, that is, $15 \times 1.25 = 18.75 \ t/m^2$ hence safe. It is seen that there is a possibility of slight reduction in the toe projection; 0.3 m x 0.45 m size could be used.

7. COMMON CAUSES OF FAILURE OF HILL ROAD RETAINING WALLS

There are a number of defects in the construction of the retaining walls in hill road and in its back filling which may utlimately lead to their failure. These are discussed below in detail.

(i) Construction of Retaining Walls just after Hill Cutting on New Roads

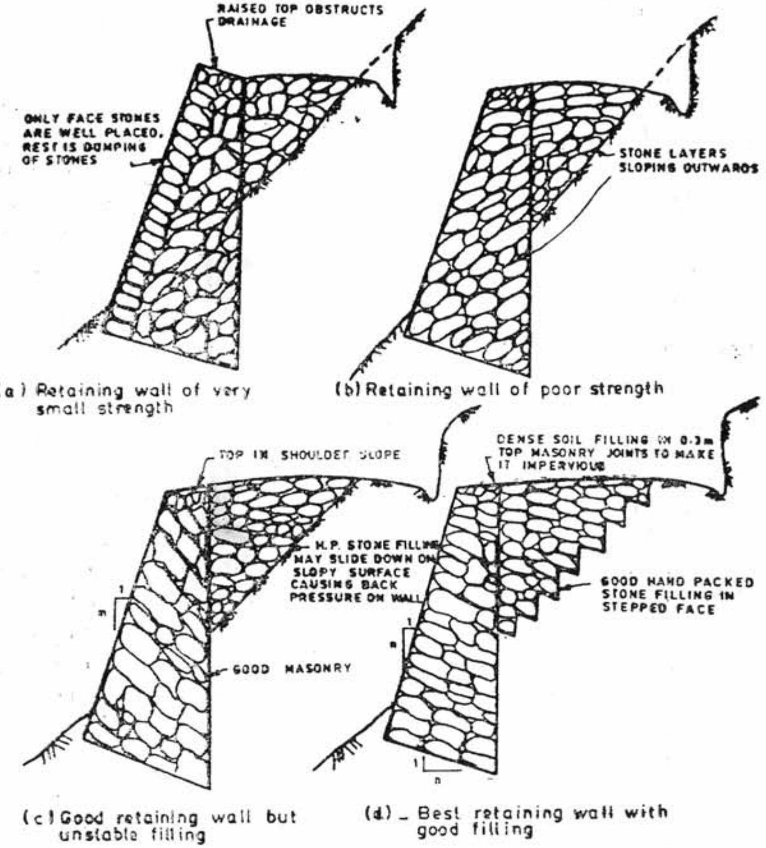
Many times, the construction of retaining walls and breast walls is done just after hill cutting is completed on the new roads. It has been observed that damage occurs much more in such cases because of disturbance caused to the stability of rock masses by blasting, hammering, etc. and which require some time to settle down. This process of settling down usually requires the passage of one rainy season during which unstable masses get slipped down. Therefore construction of retaining walls and breast walls should usually be taken in hand after the passage of one rainy season after hill cutting.

(ii) Improper Construction of Wall

The construction of hill retaining walls in far-away places is usually supervised by non-technical persons, like mates and many construction defects creep in including provision of inadequate section of the wall itself in place of the designed cross-section. Thus, there may be insufficient base width; improper slope at the base, that is, base may be made sloping outwards rather than inwards; the slope of bedding planes may be kept outward and not towards the back fill; except the facial stones, other stones in the section of the wall may not be properly bedded and overlapped for frictional bond; the section of the wall may be made less than designed along the height, etc. Such defects are noticed in most of the damaged walls, Photo 5 and Fig. 6.

(iii) Improper Backfill

Where there is inadequate quality control, the backfilling behind retaining walls is sometimes done using muck (which may not be free draining) instead of using stone and coarse grained material filling. Much larger pressures may be exerted against the wall by the improper backfill material due to its own smaller angle of internal friction and due to water which may be retained by it during rains.



(a) Retaining wall of very small strength

(b) Retaining wall of poor strength

(c) Good retaining wall but unstable filling

(d) – Best retaining wall with good filling

FIG. 6

(iv) Improper Drainage

Most hill retaining walls and breast walls are damaged during the raining season due to collection of water behind retaining walls in their backfills which exerts very large pressures on the walls for which they are not designed. This happens because sound principles of drainage behind retaining walls are not adopted at the site. Where weep holes of small size are provided in the walls, they get choked after one or two heavy rains and do not then function as desired.

(v) Seismic Action

Like all other structures, retaining walls are also shaken to the core during severe earthquakes and the pressure due to backfill is also increased to some extent. However, the effective seismic forces are not high in the case of retaining walls in contact with earth and even more so in dry masonry walls due to very high damping. It is therefore expected that retaining walls designed for the code based seismic co-efficients will be able to sustain the probable earthquake motions in the various seismic zones.

8. PRECAUTIONS IN CONSTRUCTION OF HILL ROAD RETAINING WALLS

The following precautions and quality controls are necessary during construction of retaining walls which should of course be taken in hand after one rainy season has passed after hill cutting for new roads.

(i) Proper Alignment

The alignment of the section and the hill edge clearance near toe should be done as per design specifications for the site or as standardised for the concerned zone, as shown in Fig. 6(d).

(ii) Proper Base Slope

An inward slope provides good keying of wall in the hill face and also reduces the toe pressure, besides increasing very greatly the sliding strength of the wall at base. Therefore the base should preferably be at right angle to the face of the wall. A minimum inward slope of 1 in 6 should be adopted in any case.

(iii) Good Stone Work

Rough flat stones should be preferred because they would give better contact and friction at joints. Size of stones below 225 x 100 x 75 mm (weight about 5 kg) should not be used in masonry. The largest dimension, that is, the length should be placed across the length of retaining wall for maximum stability as with this arrangement the wall facia will not easily separate away from the hearting. It shall result in greater unity among the stones placed around it. Unfortunately in common practice, the longest dimension is often placed along the wall length to give good appearance to the retaining wall. This practice promotes separation of face stones even in small vibrations, adjustments of joints during vehicle vibration, minor settlement at foundation, etc., Photo 5.

In dry stone masonry it becomes necessary to spread soil, which should be gravelly or sandy soil, broken stone dust stone chips and soil mixtures, after placing each layer of stones to fill the voids. For this purpose fine grained soils (silty or clayey) and smooth river shingle should not be sprinkled because these may lubricate the joints decreasing the frictional resistance. Only coarse angular particles should be made use of. If available in the vicinity, water should also be sprinkled to moisten the filler material and some ramming should also be done. This will be helpful in spreading the load of overlying stones more evenly and increase the weight of wall by 5 to 20 per cent which would in turn increase the strength of wall. Filling of voids will prevent filling of the cavities by mud which would be injurious to the wall since it would make the wall impervious to the flow of water.

(iv) Proper Masonry Bedding Slope

The bedding planes in the masonry should be made parallel to the base. If it is not done, the sliding strength gets reduced considerably as shown earlier (compare Eqs. 2 and 3). Stones should be rough and placed well inter-locked at close proximity with each other.

(v) Proper placement of Backfill

Dumping of stones in the wall section or in backfilling should not be done at all. Construction of masonry must of course be done by qualified masons who should ensure breaking of vertical joints. The backfill also should preferably be done by hand-packing to achieve the maximum angle of internal friction. The backfill material must be non-cohesive and as free draining as possible except the top layer of about 300 mm thickness which should be as impervious as possible to minimise ingress of water from road surface.

(vi) Proper Drainage

Efficient drainage system above retaining wall top is most necessary to reduce ingress of excessive water in backing so as to avoid possibility of excessive back pressure. This item is discussed at length in para 9.

Fig. 6 shows sections of retaining walls with a number of construction variations. The ones shown at (a) and (b) represent bad constructions liable to damage or failure of the walls and those shown at (c) and (d) exhibit good constructions to achieve stable conditions. It is sometimes seen that the excavated material from foundation is dumped by the side of the toe which obstructs drainage. It should never be allowed this way and must be sloped down below the top level of the toe projection.

9. DRAINAGE BEHIND HILL ROAD RETAINING WALLS

Besides proper construction of the retaining wall masonry, drainage of water behind the wall is the next most important factor for achieving long-range stability of the retaining walls. There are two steps in the solution of this problem; the first is to avoid the water seeping into the backfill material and the second is to drain off whatever water gets into it as fast as possible to prevent the saturation of the backfill. Another precaution to be taken is to save the percolation of water to the soil under the toe of the retaining wall because it is at that point the soil is subjected to the maximum compressive stress. The suggestions to achieve good results are given below:

9.1. Preventing Seepage of Water into Backfill

The backfill material in the top 300 mm thickness should be kept as impermeable as possible and thoroughly compacted. It should be laid at a proper camber and shoulder slope. The water flowing in the hill-side drain should be drained off through scuppers of appropriate design at regular intervals. In no case should the retaining wall top be higher than shoulder but rather slightly lower and sloping outward so that the water runs over the wall instead of seeping into the backfill.

9.2. Weep Holes or Drainage Holes

Weep holes are vital for drainage of underground seepage water particularly in soil zones. Conventional size of weep holes is 100 x 150 mm with 1 : 10 downward and outward slope. It is frequently seen that such weep holes are choked up by silt and fine soils and it is very difficult to keep them open. The very purpose of providing such weep holes is therefore many times defeated. Dry masonry walls of good construction (See para 8) have the advantage that the masonry remains quite permeable to the flow of water and pressure build-up is normally avoided.

9.3. Pressure Relieving Scupper Type Holes

It is seen in the field that high retaining walls with scupper openings are rarely damaged, Photos 4 and 6. The scupper opening drains out all the seeping water coming from all sides and the water pressures reduced to almost zero above its bed. Such scupper type large holes may be provided at a depth of about 4 m below road surface and at horizontal spacing at about 6 m centre to centre, Fig 7. Obviously the seeping water

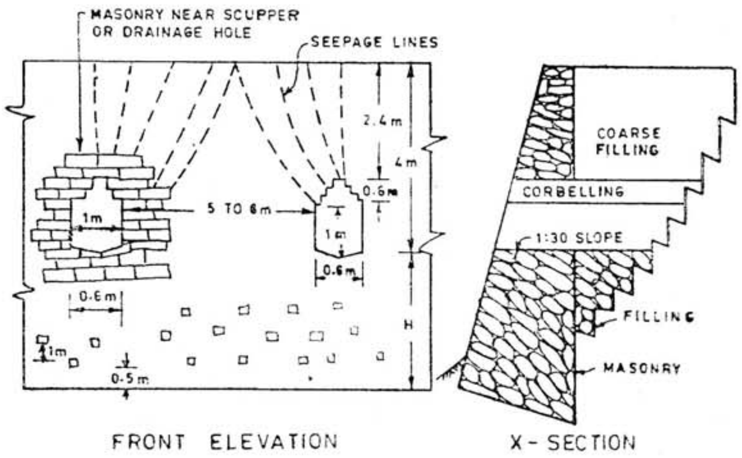


Fig. 7. Drainage Scupper

coming toward the bed level of the scuppers from top shall be fully drained out. Therefore the water pressure will become zero above that level.

These scupper openings can be inspected and cleaned without difficulty since labourers can enter into the openings very easily. There will also be added advantage of quality control as this will conclusively give idea of the section of wall provided and the width of stone filling. A 1 : 15 to 1 : 36 bed slope should be provided in the scupper opening. The masonry joints in the bed should be filled up by impermeable fine soil or fine stone dust so that water may not creep-in below the bed.

9.4. Dissipation of Falling Water Energy by proper Toe Wall

High velocity water falling from top of retaining wall can cause soil erosion at toe and even below it by back erosion of even soft rock or shale. A large number of walls may be observed to collapse due to this reason because it is here that the maximum compression and over-turning action occurs. Toe of many retaining walls may be seen eroded after the rainy season, Photos 7 and 8. It should be repaired by filling of stones tightly into the pocket. The impact and energy of falling water can only be dissipated by constructing a proper toe wall in soft rock and soil reaches. A fortunate factor is that the wall is not damaged all of a sudden due to toe erosion. Arching action across eroded pockets takes place in masonry to resist collapse but this can protect upto some certain limit only and before that the cavities must be repaired. The utility of toe wall is to distribute the pressure to a wider area and to dissipate the falling water energy by hydraulic jumps, Fig. 8. It should be a general practice to provide some minimum toe projection at the base of each retaining wall except where the toe rests on hard non-erodible rock.

10. SECTION OF HILL ROAD RETAINING WALLS IN VARIOUS ROCK ZONES

The required safe section of retaining walls will depend on the unit weights of masonry and backfill materials, the angle of internal friction of soil, the height of the wall, the

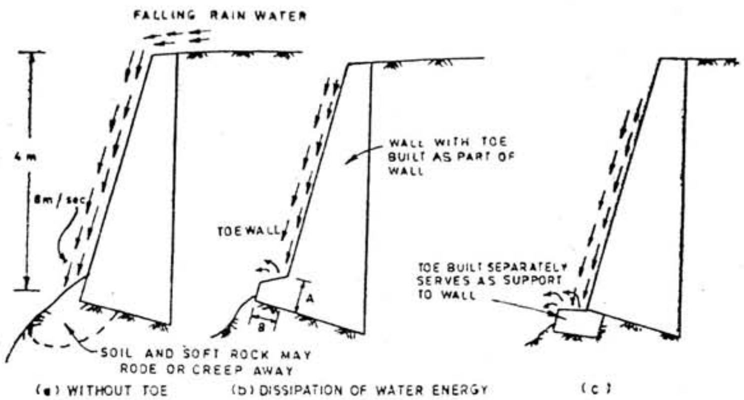


Fig. 8. Construction of Toe Wall

design seismic co-efficient and the allowable pressure on the base of the retaining wall. If water is allowed to collect and saturate the backfill, the lateral pressures on the wall will increase manyfold and even a well designed mortarred wall will be endangered. Therefore, in all retaining wall designs it is presumed that free drainage of water will remain available. The good features of the retaining wall section are shown in Fig. 6d in which

(a) the top width of wall is 600 mm;

(b) the earth face of wall is vertical;

(c) the face has a slope n : 1 where n depends on various design parameters;

(d) the base has an inward slope either 1 in n or minimum 1 in 6;

(e) there is a toe projection to resist the scouring and softening action of water at the toe of the retaining wall in erodible beds;

(f) the stones in the wall body are placed in courses with their bed sloping inwards, parallel to the base;

(g) the backfill consists of hand-placed stones or coarse grained soil, and the lower supporting surface of hill is stepped; and

(h) roadway top is finished with relatively impervious layer about 300 mm thick.

Values of the face slope factor n and the dimensions of toe projection, found to be theoretically safe, for the various parameter combinations are recommended in Table 5.

Besides the above general recommendations specific suggestions about certain site conditions are given below :

10. 1. Toe Projection

The toe projection is necessitated firstly for protecting the soil under toe from erosion and secondly for reducing the intensity of compressive stress. Provision of toe projection is a must where either the whole base of the wall rest on over-burden material or only a part of the width which would necessarily include the toe rests on such erodible material, Fig. 9. The toe projection could be built as a part of the section of the wall or as a separate toe wall part of which will support the toe of the retaining wall as shown in Fig. 8.

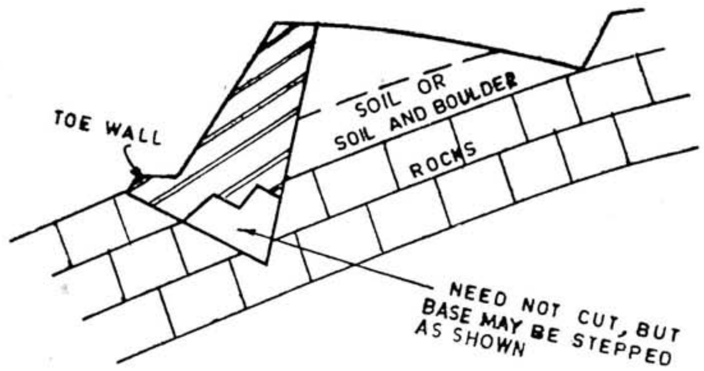


Fig. 9.

10.2. Reduction of Rock Cutting at Heel

In case where the hill near retaining wall top consists of soil, soil and boulders or soft rock, and the rock near its base is hard like hard shale or other harder rocks, the foundation slope and the face slope of the wall may be reduced as per the strength requirements. Toe wall is also not necessary in unerodible rocks. Also the cutting of rocks may not be necessary at heel side but it may be stepped to give good seat to masonry as shown in Fig. 9.

10.3. Rocks and Boulders with Inward Dip

Such zones are very stable and firm. Base slope may be reduced upto 6 : 1 (6 horizontal to 1 vertical) and face slope may also be reduced to 6 : 1 if indicated by strength calculations. Base may be stepped to give good stable seat to masonry stones. Toe wall is not necessary but hill edge clearance should be about 300 mm for wall heights upto 6 m and 600 mm for larger heights to avoid any chance of toe failure.

10.4. Rocks and Boulders with Outward Dip

These zones are comparatively unstable particularly when fractured since any boulder may separate and move away. In such zones, base slope should preferably be 3 : 1 and so also, the face slope should be 1 : 3 to 1 : 6 depending upon the firmness of rock. Base may be suitably stepped to give good seat to masonry stones and the back filling stones. Foundation should be taken to 600 mm depth for wall heights upto 6 m height and 1 m for wall heights above 6 m, to avoid any chance of toe and base failure. Any gap should not be left between hill face and toe of wall.

10.5. Masonry with Round or River Boulders

Retaining walls upto 6 m height may also be constructed by round egg-shaped boulders with a good strength. The boulders should be so placed as to have maximum area of contact and stability each and to result in a well-packed masonry mass. The inward slope of bedding planes parallel to the base is extremely important in this case. The joints and voids between the stones should be filled by spreading granular soil mass, consisting of sand, stone dust, grit, etc., but fine soils and river shingle must be avoided. Sprinkling of water will be very useful. The size of at least 50 per cent stones should be such that each does not have less than 10 kg weight, Photo 9.

11. ENSURING INTEGRITY OF DRY STONE MASONRY RETAINING WALL SECTION

As stated earlier, the dry masonry walls shall be stable in all conditions, as much as the mortarred walls, provided that their integral action both horizontally and vertically could be ensured. The only binding force between the individual stones is the friction which would be available if the stones in consecutive layers are properly overlapped with each other. In thicker wall sections, as become necessary for tall rataining walls, this necessity of bonding will be called for even to a greater extent. In the opinion of the Authors, this could be best achieved by using special bonding elements through the masonry, going from the earth face of the wall to its front face at regular spacing along the length and height as shown in Fig. 7. The elements could consist of wooden ballis or bamboos too, but considering the durability aspect, the following arrangement is recommended.

The bonding element (Fig. 10) may consist of reinforced concrete member square in cross-section and having a length equal to the thickness of the wall plus 150 mm so that it may project out of wall by 75 mm on both sides for easy checking. It will also give an idea about slope of masonry layers. The surface of the concrete should be made rough by using wavyness or key-projections in the moulds on the two vertical

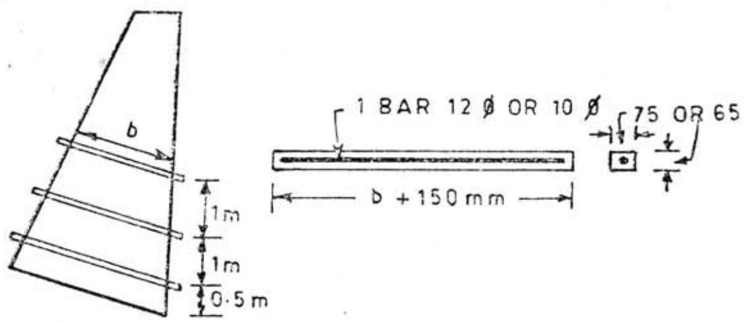


FIG. 10 – BONDING ELEMENTS

sides of the mould or criss-cross lines be marked on all sides. Each element should contain one reinforcing bar of deformed type, the diameters being kept 12 mm for element lengths 2.6 m or more which must have 75 x 75 mm cross - section and 10 mm diameter in 65 x 65 mm cross - section for smaller lengths. Such elements need not be provided in the top 4.0 m height of the walls. One such element may be laid every 1 m spacing measured vertically and horizontally starting with the first layer at 500 mm above the base.

To avoid site work involving use of cement and water, the elements may be cast at Divisional or Sub-divisional head-quarters in various standard lengths and stored, and then carted to site of the wall in required numbers and lengths. Any extra length at site can just be left projecting in the backfill. The effect of the projection in the backfill will be advantageous in increasing the wall friction angle and consequent reduction in earth pressure. These elements will provide the necessary bond between the stones and resist their slippage, if any, through the tensile strength of the reinforcing bar.

12. PRACTICAL AND ECONOMIC CONSIDERATIONS

There is great shortage of cement in the country, and it should be saved to the maximum extent particularly where it is not absolutely essential to use it. Since hill-retaining walls can be constructed in dry masonry only without any loss of strength and safety, this is one situation where its use should be avoided altogether except in the bonding elements. There is also usually acute shortage of water in hills. If a water tap or natural source is not available in the vicinity of construction site, the cost of water may work out to a couple of rupees per tin of 16 litres of water. In such situations, it is practically impossible to fetch enough water in making workable mortar and prior wetting of stones and then curing. It may often be seen that stiff mortar is spread over dry stones which does not fill up the cavities. Curing of bands and fully mortarred masonry to proper requirement becomes completely out of question: firstly due to paucity of water; and secondly for continuity of construction after laying the bands. Thus the bonding effect of cement mortar remains very doubtful and

lack of bonding may be observed in most of the damaged walls. In most cases the mortar in existing walls can be powdered by fingers only. Thus the purpose of providing bands or fully mortarred masonry is defeated.

The costs of banded and fully mortarred masonry retaining walls are three to ten times that of a dry stone masonry wall. Therefore in place of one mortarred masonry walls, ten dry masonry walls of equal length each may be constructed. The economy and benefit to the State is obvious.

Dry masonry walls have the added advantage that after collapse of a dry wall, it can be reconstructed by labour only in a few days, while reconstruction of a banded or fully mortarred masonry wall shall involve much money and time, provided, that cement is readily available. Consequently it will cause much inconvenience to the traffic because of closing of road for a long time.

The above considerations of safety and economy as well as practical feasibility prove beyond doubt that dry stone masonry walls are sufficient for various purposes in case of hill road retaining walls and breast walls. These may also be used for building site developments with great advantage, in which case, however, use of bonding elements may be done for all heights and at closer spacing for achieving greater integrity of wall and hence better safety.

13. CONCLUSIONS

This study has highlighted the observed behaviour of retaining walls of hill roads in the field, listed the main factors leading to their damage or failure and suggested the precautionary measures and steps to ensure long-term stability of the walls at minimum cost. The standard design criteria for stability and the observed behaviour of various types of retaining walls point out to the following conclusions :

(1) There is no particular utility of bands or fully mortarred masonry in hill road retaining walls except for ensuring the integral action of the stones only if the construction is

properly carried out according to specifications, which generally does not happen due to practical limitations and difficulties in the field.

(2) Failure of large number of retaining walls of all types every year during rains shows the ineffectiveness of bands or supposedly fully mortarred joints in checking complete or even local toe failures and unequal settlement of foundation.

(3) Dry stone masonry retaining walls can be constructed for all heights safely as well as much more economically when reinforced with special bonding elements as suggested.

It is, therefore, strongly recommended that the use of banded and mortarred stone masonry retaining walls should be discontinued in hill road retaining walls and replaced with dry stone masonry walls reinforced with bonding elements. Suitable standard specifications need to be drawn up for this purpose which could be done with the help of data presented in this Paper.

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2. " Technical Instruction No. 5. Retaining Walls ", Chief Engineer, U. P. P. W. D., dated 25-8-60.

3. Leonards G.A., " Foundation Engineering ," McGraw Hill Book Co., 1962, p. 218.

4. " IS: 1893—1975, Criteria for Earthquake Resistant Design of Structures ," Indian Standards Institution, Manak Bhavan, New Delhi, 1976.

and may not have been reported in this Paper, for carrying out the work further and taking care of all the points that have been raised in the discussions today.

Another aspect is that of a ready reckoner for the field engineers, which this Study, as pointed out by **Shri Kadiyali** is not an end by itself, but a catalytic agent. The Study has covered luminous ground on a rational basis removing the past *ad hoc* and generalised reasonings.

Discussion on Paper No. 356

"RETAINING WALL FOR HILL ROADS" *

By

DR. A. S. ARYA AND V. P. GUPTA

Monday, 9th January, 1984

Brig. Gobindar Singh (*Opening Remarks by the Chairman*)

Dr. Arya is not with us today ; therefore I would request Shri V. P. Gupta to present the Paper.

Although the subject of the Paper is limited in the context of hill road construction, still it covers a very important aspect as no hill road can be built economically and be fully functional without a series of retaining structures. These absorb a fairly heavy percentage of the total cost and financial outlay on the construction of road in hilly areas. It is, therefore, necessary that we apply our mind to make economical methods of construction and design of such retaining structures. The Authors have tried to analyse the problems and make some definite recommendations. I would only like to mention here that the Paper deals with one set of conditions as well as certain parameters which may not be applicable universally. Further, the recommendations as long as they achieve economy and also fulfil the stability criteria, are worth discussing and considering along with other similar measures. The subject obviously is very useful and relevant for all the hill states as well as the Border Roads Organisation. The Paper is now thrown open for discussion.

* Printed at pages 291 to 326 of the Journal of the Indian Roads Congress, Vol. 44, Part 1.

Shri M. L. Bansal (*Co-Chairman's Remarks*)

Dry random rubble masonry retaining walls for hill roads can be built for all reasonable heights, as long as adequate frictional bond is developed from back to face and base to top, ensuring the entire wall to behave as one unit. Use of roughly dressed rectangular stones with inter-locking and sufficient overlap can achieve the above aim.

From overall stability and sliding considerations, the random rubble masonry wall is in no way inferior to the fully mortarred or banded type or retaining wall with bands. In fact from seepage considerations, the dry stone retaining walls are better suited, as it facilitates easy drainage reducing the tendency to build up undesirable pressures. Such walls are less affected by inadequacy of curing as compared to the fully mortarred walls.

Cost of dry random rubble masonry retaining wall is generally half that of those with bands and about 1/3rd that of fully mortarred random rubble retaining wall.

In case of very high retaining walls, however, it may be preferable to give one course of cement concrete 1 : 4 : 8 throughout the section both length-wise and breadth-wise of the retaining walls to break the joints and to cover up any shortcomings in the execution of dry stone retaining walls.

The filling behind the dry stone retaining walls in at least 2 to 3 ft. width should be done in stones properly stacked and further filling of earth-work should be done in layers and rammed; and the top surface sealed with bituminous macadam to prevent any unnecessary seepage of water increasing the pressure behind the retaining wall.

Dr. A. S. Arya and Shri Y. P. Gupta (*Introductory Remarks by the Authors*)

Expenditure of several crores of Rupees is incurred every year on construction and maintenance of hill road retaining walls. In the prevalent practice, retaining walls upto 4 m height are constructed in random rubble dry stone masonry (DRM)

and the higher ones are built as in masonry with bands or in full cement or lime mortar. These are based on thumb rules irrespective of the nature of site and the engineering properties of base soil, rock, backing mass, etc. A large number of retaining walls of all types do collapse during rainy season and they are reconstructed having same or stronger specifications.

This Paper emphasises that hill retaining walls could economically and safely be constructed in dry stone masonry for all heights and provides appropriate details to be used in planning and construction to achieve these aims.

The first and the foremost assuring point is that a large number of DRM walls upto 10 m height are standing quite well for the last so many years and even decades, examples of which are shown in the figures in the Paper.

Secondly, on the basis of design criteria and on comparing the stability strength of all types of walls, their strengths are found almost the same, because for the given site conditions and same dimensions of walls they have same strength against sliding, tilting or over-toppling. Basically, the strength of masonry walls depends on angle of internal friction between stones used, direction of bedding planes in masonry, the base width, and weight of wall. If a weight 'W' is placed on a frictional surface, the force required to move it up a slope of 3 : 1 is 2.23 W, down this slope 0.43 W and on a level bed 1.05 W for the case cited in Eqs. (4) and (5). The bedding plane slope therefore very much determines the strength of dry retaining walls as illustrated by numerical values in para 4. The practical implication is illustrated in Fig. 6.

Hill road retaining walls' geometry, cutting and filling can be done as in Figs. 3 and 4 and Table 5 of the Paper. It may be designed as in Paras 5 and 6 and values given in Tables 5 and 6.

A large number of retaining walls of all types collapse in every monsoon—sometimes even in winter monsoon, because of a number of reasons such as the following :

(1) Construction of retaining and breast walls soon after cutting ; since they do not get proper firm and stable base and receive huge back pressure because of unstability caused due to blasting, cutting, etc.

(2) Improper construction due to lack of supervision regarding full section, placement of stones, etc., as clear from Photo 5 and Fig. 6.

(3) Improper back filling, such as dumping of stones may cause much pressure.

(4) Improper drainage of back-fill which is the most important point for collapse. The drainage holes of normal size 10 cm x 15 cm get choked.

(5) Softening of toe soil and rock and toe erosion during monsoon as shown in Photos 7 and 8 and Figs. 4 and 5.

The following precautions are suggested :

Proper alignment as per Fig. 4 and use of good stone work, proper stone masonry bedding overlapping each other, proper back-fill, and proper drainage on top and through the body of retaining wall. For ensuring integrity of dry stone masonry, the provision of R. C. Bonding elements shown in Fig. 10 may be adopted. Retaining walls could also be made of river boulders with precautions as shown in Photo 9.

Some important facts against walls fully mortarred and with bands are:

(1) Immense difficulties in execution of proper quality cement work due to acute shortage of water for construction and for curing of masonry at sites in remote places.

(2) Construction time of such masonry wall is much longer than dry masonry.

(3) Cost of a fully mortarred wall and walls with bands is about 10 to 3 times of similar dry walls.

(4) Reconstruction of DRM after wall collapse is much faster with the available rubble whereas those requiring use of cement will cause a lot of delay in re-opening the road.

Therefore much cement is practically wasted in mortarred walls and those with bands which could be saved by adopting dry masonry walls, providing only precast R. C. bonding

elements only in tall retaining walls. Besides, saving in cement, economy in original construction as well as reconstruction will be greatly achieved.

Shri R. K. Saxena

I would like to make some observations regarding the design aspects :

(i) In case of an improper back-fill using earth (even muck—as maintained in para 7 (iii)—page 313, the live load surcharge will also come into play for the section shown in Fig. 3 and contribute towards failure of the retaining wall. This aspect has not been mentioned in the Paper.).

(ii) Though the Paper advocates that bonded masonry is not necessary from design and economy considerations, still it considers its use for ensuring integrity of the wall, in Section 11. It is felt that adoption of bands may not be of much use where smooth finished stone faces exist. Further, these are likely to be used as ladders to climb the wall, thus contributing to the disturbance of the wall.

(iii) Weep holes (or drainage holes) and pressure relieving scupper-type holes for relieving of hydrostatic pressure on retaining wall will have to be adopted judiciously depending on the height and section of the wall. The weep holes could be provided of PVC pipes and their size adjusted as per site requirement instead of following the conventional sizes. Similarly, the scupper size recommended in para 9.3, Fig. 7, could be suitably adjusted as per site requirements.

(iv) The provision of a proper toe wall for dissipation of falling water energy is no doubt a necessity but only its provision as indicated in Fig. 8 will not relieve the problem of scour at the toe of the retaining wall altogether. It is essential that proper training of the falling water beyond the toe wall is also simultaneously done to ensure that back erosion does not get extended till the toe. This could be achieved by providing a sloping stone pitching in the form of mini-launching apron in front of the toe wall for a length governed by the site condition. Of course, this will not be necessary in case of hard non-erodible rocky beds.

Coming to the practical aspect, it has been correctly said under para 7 (ii) that the construction of hill retaining walls in far-away places is normally supervised by non-technical persons, like mates and many construction defects do creep in. As such, it is essential that proper control during execution should be exercised. For this the field staff should be trained and briefed periodically.

Shri A. Sankaran

The Authors have advocated the use of hand-packed dry stone retaining walls upto heights of 10/12 metre over the mortarred type or walls with bands as the former are considerably cheaper, offer better drainage, are free from ills of inadequate curing, etc. However, the suggestions for better construction practice such as bedding planes tilted 1 in 6 inwards and right angles to the wall face, properly designed and constructed drainage channels, adequate toe-protection etc. need to be vigorously followed. Further, the suggestion of R. C. C. ties with suitable spacings is also a well-known past practice. The use of such ties to connect up the face cores of 'wide' retaining walls is an age-old practice. Usually, 20 to 25 mm or even bigger diameter bars are used with threaded ends, and bolted to end plates, which are anchored to the undisturbed rock face. The use of netted wire mesh on the faces with linking wire-rope ties, ends looped and tightened with twin buckle is quite common, introducing certain lateral pre-compression and better structural inter-locking of stones and hence better integrity of the layers of the retaining wall.

The Paper, though advocating cost savings by introduction of R. C. C. ties, over dry stone retaining wall with bands or stone masonry retaining wall, is very vague in providing the actual costing data.

Assuming a retaining wall 10 metre high with top width 0.8 metre and base width 4 metre, and width of 1.5 metre

at 4 metre from the top, and providing such tie members for bottom 5 metres portion, and considering average length of tie member as 6 m each, such R. C. C. tie members would cost about Rs. 60 each (12 mm bars and 7.5 cm square R. C. C.) and in 10 m width of such wall, we may have to use about 60 Nos. of R. C. C. tie member, costing an extra Rs. 3,600. The basic cost of dry-stone retaining wall, including labour, etc. would be Rs. 100 to Rs. 110 per cubic metre, and with bands in C. M. 1 : 6 as per IRC design, would be around Rs. 130 per cubic metre, and the extra cost would be Rs. 4,500 to Rs. 4,800 in extreme conditions. It would thus be seen that cost-wise, there is hardly any savings. R. C. C. tie members would consume scarce cement, whereas, for bands lime mortar can also be used.

Besides, operationally introduction of R. C. C. tie members would pose constructional problems. Obviously, they cannot be 'in-situ', as casting, curing, etc., would become a problem along with attendant delay in progress. Pre-cast R. C. C. ties would pose problems in transportation and breakage while in transit and placing in the inclined position in the retaining wall and bedding the same into the stone wall layers. This is not going to be a panacea. Defective site execution with innumerable such holes not properly packed, could act as potential seepage channels and also lead to subsidence of the fill.

If masonry mortar is not adding to the cohesion and integrity of the masonry, why should IS Code 4326 prescribe brick masonry in cement mortar less than 1 : 6 mix as mandatory for brick masonry in load-bearing masonry buildings, for seismic zones III and above ?

The Paper needs to provide more actual and factual statistical data on failure mechanism and the extent of failure as noticed in the case studies between dry stone retaining walls and retaining walls with stone masonry band layers of comparable situation, so as to precisely quantify the severity of failure. Further, the cost data on dry masonry retaining wall type without tie bars and with tie bars, (dry type with bands, etc.), should be precise so that a better quantitative and qualitative appraisal can be made.

Shri C. Rama Rao

In para 9 of the Paper, it is mentioned that the back-fill should be kept water-proof so that the seepage of water can be avoided. It has also been mentioned that clay should be avoided, as it may act as a lubricant, when it comes in contact with water.

In my opinion, a 6 per cent addition of clay mixed with graded stone chips and sand, in the back-filling, particularly on the top layer of back-filling, will make it water-proof at a cheap cost.

In para 9.1 of the Paper, it has been stated that the top of the retaining wall should slope outwards for drainage of water. It is the normal practice to erect parapets on the retaining wall, which would require a horizontal surface. Moreover, each layer of the stones of the retaining wall is sloping towards the hill. Is there any harm if the entire slope of the road surface is kept towards the hill-side drain. I would request the Authors to elucidate this point.

Shri J. S. Marya

I do not agree that provision of pucca masonry bands in cement mortar are useless in retaining walls. In fact they have a definite purpose to perform in respect of strength and durability of retaining walls. A study of old retaining walls of different types in different terrains would prove this point beyond doubt.

There can be various types of retaining walls that one can think of and the adoption of a suitable type will depend on terrain conditions such as rainfall, snowfall, seismic conditions, etc. The types of retaining walls, I can think of, would be a retaining wall or breast wall in soil-cement block construction cast-in-situ. I remember the use of such a type made in heavy rainfall area near Dharamsala in Kangra District, Himachal Pradesh more than 20 years back at a seriously

troubled spot where such a remedy was adopted in consultation with the State's Research Laboratory and it proved a very good stitch in time, having excellent long-lasting performance. The other types can be stone in wire crates. In the case of CR masonry retaining walls, one can consider trying PVC rods with thickened ends as bonding elements. Even in Indonesia, I had observed use of stone in wire crates for retaining walls. At places even retaining walls are back anchored into wooden piles driven into the back-fill. At places where the road runs into tough and steep rock formation, the back anchorage of retaining walls into rock is found to be a very useful arrangement. In tough rocky situations, sometimes the reverse or back batter slopes are provided to the retaining walls instead of front face batter so as to provide maximum road widths.

For stability of retaining walls, the road drainage at the location has to be very carefully planned, both for design and construction, as also subsequent maintenance. Where a retaining wall also accommodates within its length a draining culvert, frequently it has been found that the discharging point of the culvert causes lot of scour specially where the culvert discharge falls out, over the face of retaining wall or at the toe of retaining wall. Such discharging points must be properly treated by providing a non-eroding treatment at the outfall.

Shri S. C. Gupta

One of the suggestions made in the Paper is to provide R. C. C. members at 1 metre centre to centre horizontally and vertically to cause integrity of dry stone masonry wall with back-fill. Passing reference has been made about the use of ballies/bamboos but has not been recommended in preference to R. C. C. members on considerations of durability. Transporting of cement and steel from plains and sand from valleys, required for construction of R. C. C. members will be a very costly proposition and will form a substantial percentage of the cost/sq. metre of retaining walls. It is, therefore, essential that we must consider use of local wood or bamboo materials which have already been withstanding the local environments since long. The durability can be improved by painting with paints already available in the market, which will be adequate for the period required for the economic viability resulting in considerable savings. Such arrangements have been adopted for construction of retaining walls on hill roads in Nepal. Besides use of bamboo mattings horizontally at specific vertical intervals have also been adopted. Use of bamboo mattings horizontally give a band effect resulting in added advantage under seismic loads. Our experience is that such arrangements have stood well for the period required, as after some period of time the earth-fill itself develops natural compaction with the passage of traffic resulting in increased angle of repose and thereby giving a relief to the retaining wall.

The use of wooden ballies, bamboos and bamboo mattings will go a long way in reducing the cost of construction without sacrificing the structural stability and durability for the required period besides conserving construction materials like cement and steel.

Shri M. S. Guram

The assumptions that the wall will act as a single mass, in the stones arranged in a certain manner may not be so. In fact most retaining walls failed because they did not act as one mass.

The two stones being irregular and not perfectly horizontal or vertical, contact may be at a few points with pressure being very high at the points of contact, where failure may occur. These types of failure will be irregular and at weak points. Regarding the bond rod proposed, it may be difficult to handle and in fact the transfer of force by bond between the stone and the bars do not appear to be very safe as the area of contact is small. For the retaining walls with band it has been observed that the bulging of the retaining walls at the dry portion is much more than the bulging at the bands. In fact, the failure of the retaining walls start at the dry masonry portion. We should, therefore, study the failure of the retaining walls and the actual field conditions before thinking of any change in our specifications.

Shri J. S. Sodhi

The Authors have tried to replace one form of bond in the retaining wall with another to attain homogeneity. In some specifications, the bond is attained by bond stones 2 ft long overlapping each other by 6″ and spaced 5′ c/c in the course, while in the others, cement masonry bands are provided. In the absence of natural bond stones, cement concrete bond stones have also been used. Basic defect in the system of construction being inadequate supervision. But the new bond rods or battens as proposed will not fit in the overall bond system of masonry retaining wall, being of lesser height than the stone.

I agree with **Shri Marya** that crated stone masonry retaining walls will be very useful in unstable hill slope areas, and they have been tried with success in J & K areas.

Quite a few specifications recommend that no weep holes are necessary in dry stone masonry as the masonry is self-draining. This is a misnomer. It has been noticed that these crevices get filled with earth and growth comes up, thus completely blocking the water path. It is, therefore, essential that weep holes are provided in the dry portion of the wall also at 5′ c/c. A system of dispersed weep holes will behave better than the large hole proposed by the Authors. A large number of such walls have been constructed in snow-bound areas.

Shri O. P. Gupta

The observations made in para 12 that the cost of mortared walls are likely to be 3 to 10 times that of dry stone masonry wall, needs re-consideration taking into account, the life, the future cost of maintenance and upkeep, the element of risk for the same degree of structurals' performance and lastly that both types are built as per proper specifications. From the point of view of saving cement and using it for other important structural elements, the specification for dry stone rubble masonry needs consideration, subject to its structural soundness.

Shri S. N. Mane

I agree that use of cement mortar (full or banded) masonry retaining walls should be replaced with dry stone masonry construction in the interests of economy. The preference for dry stone retaining walls and actual construction for heights of over 45 ft has been reported earlier in the IRC Paper No. 257 (vide Paras 7.7.1.1, 7.7.1.6 & 7.7.1.7) "Construction of a Ghat Road" by Shri E. C. Chandrasekharan published in IRC Journal, Vol. 30-1 of June, 1967.

However, the use of cement mortar masonry with anchor/dowel bars would be preferable in the bottom layers of retaining walls with steeped foundations in rocks till the requisite section width is achieved and in the top 0.5 m or so of the walls (to act as coping) to avoid seepage of water and dislodgement of stones from top layers. For the purpose of design calculations in this Paper, walls with front batter and back vertical only have been considered. In this connection, it may be stated that walls with front vertical and back batter have certain distinct advantages and are economical, as reported in IRC Paper No. 298 (vide para 8) " SPR Project in Nepal " by Shri V. A. Khaire, published in IRC Journal, Vol. 35-4 of January, 1975 and " A plea for vertical front faced retaining walls in hill roads " by Shri T. G. K. Reddy, published in Indian Highways, Vol. 10, No. 8 of March, 1982. These should be given a fair trial and their structural performance and economy accruing thereafter may be judged.

A few points on construction practices :

(a) It has been stated in Para 8 (iii) that the largest dimension (*i.e.*, length) of stone should be placed along the length of retaining wall for maximum stability. A better practice would be to place stones in header-stretcher arrangements with 2 or 3 stretchers followed by one header and proper breaking of joints in successive courses.

(b) It has been stated in Para 8 (iii) that it becomes necessary to spread soil after placing each layer of stones to fill voids. The levelling is required more to provide proper bedding and structural support for the next course and not fill voids. Providing a levelling course with the aim to fill voids should be discouraged as it tends to be thick initially during construction and settles subsequently due to seepage through the voids. The desirable practice for such levelling is to use stone spalls locally available from the stone dressing done at site. This way, excessive quantities for levelling would not be available/used and the quality of levelling material would be the same as that of masonry stones.

(c) In has been stated in Para 9.1, that in no case should the retaining wall top be higher than shoulder but rather slightly lower and sloping outwards so that water runs over the wall instead of seeping in the back-fill. This may not be always desirable. In fact at certain locations with erodable toe material, better practice would be to provide the top of wall slightly higher than the shoulder and to make shoulder water-proof so that the water is drained out to the hill-side drain instead of topping over the wall and eroding the toe.

(d) The suggestions to provide scupper-type relief holes (*vide* para 9.3) has certain advantages but the section (1m x 1m) is considered rather large. With the passage of time and disintegration of corbelling stones, sudden collapse/caving in of the wall and back-fill are known to have occurred. It is suggested that the section may be 0.5 m x 0.5 m and pre-cast slabs should be provided wherever good corbelling stones are not available.

(e) For walls on rocks and boulders with outward dip (*vide* Para 10.4) dowel/anchor bars in masonry/concrete casing should be provided for better stability.

(f) In case of masonry with round boulders (*vide* Para 10.5) even if proper dressing is not possible, it will be desirable to break the boulders so as to have at least 2 or 3 fractured faces, instead of using round boulders in their smooth shape. For filling up the joints between boulders, spalls obtained from broken boulders, should be used instead of soil, sand, stone, dust, grit, etc.

(g) Apart from various precautions in construction, brought out in the Paper, a simple precaution of back-filling the toe of the wall is often not taken, which results in ponding of rain-water leading to weakening of the foundation soil and erosion of the toe below the foundation. Back-filling at the toe of the wall, turfing or pitching wherever possible should form the part of the finishing after the wall is completed.

Shri S. R. Tambe

The slip of soil below the base of the wall has not been touched in detail in the Paper. Some explanation on it would be useful.

The example on pages 305 & 306 is not clearly understood. The values of *Ca* worked out are not seen in Table 4.

On p. 302, 'λ' has remained to be printed probably.

Passage of one rainy season after cutting but before constructing the wall is advised on page 313 but may not be possible in many cases due to the problem of accessibility.

For proper drainage of back-fill, do the Authors not feel the need of filter behind the walls when the back-fill is of toils ? Also on the roof of scupper-type drains and at their ends ?

Shri K. S. Desai

It is seen that the effect of live load surcharge has remained to be accounted for. This can also be confirmed from the example solved on Page 305. Authors may consider the effect of live load surcharge which contributes a sizeable force.

Earth pressures have been calculated by Coulomb's Theory. The point of application of the force as per Coulomb's Theory should therefore be at 0.42 *H* and not 0.33 *H* as per clause 217.1 of I. R. C.

Similarly structures designed to retain earth, are also to withstand a horizontal pressure not less than that exerted by a fluid weighing 480 kg/cu m. This check has remained to be exercised. With this check the base pressure exceeds the assumed allowable pressure. For high angle of internal friction, this check also becomes a guiding factor.

The Authors are proposing toe projection of 0.45 m wide and 0.675 m high. For large heights of wall, the advantage of base projection need not be taken, and if this is taken, a section immediately above this projection needs checking since it may prove to be critical.

To avoid total failure, *i.e.,* to localise the failure, with bands walls need consideration, even after taking into consideration the paucity of water in the locality.

Shri K. C. Bansal

The Authors have recommended dry R. R. stone masonry retaining walls and that the bonded or fully mortarred retaining walls be avoided altogether for economical considerations. For this purpose, case studies giving the performance of dry masonry wall *vis-a-vis* mortarred or walls with bands both built as per specifications and in identical environmental conditions has to be reported. The view that a large number of R. R. dry stone walls of heights more than 10 m has been standing well for many years, whereas, fully mortarred or bonded retaining walls with bands have collapsed, cannot be idealised.

In para 5, the Authors have given six nomenclatures of rocks and stated that 1 to 5 are hard materials which by themselves are quite stable. Shales, specially soft shales are not stable, when wet during the rainy season, shales crumble and get dissolved on prolonged exposure to water.

In para 7, the Authors have suggested construction of retaining walls and breast walls, after the passage of one rainy season, after free cutting. It is alright for breast walls but not so for the retaining walls. Moreover, delay in completion of the road by one year would deprive its benefit by one year and would result in higher cost of construction of retaining walls due to cost escalation and re-arranging most of the stones required. Further, the slip is mostly retained on the cut portion of the hill which does not effect the retaining. Regarding bonding elements mentioned in para 11, stone walls should be used wherever available ; otherwise R. C. C. stone wall should be used with sufficient overlap. The Authors have not mentioned anything about this overlap. We cannot think of constructing very high retaining walls in R. R. dry masonry without studying the problem in totality. Just because a few high dry R. R. walls are standing, is no justification for adopting them on large-scale indiscriminately.

Shri K. S. Rakshit

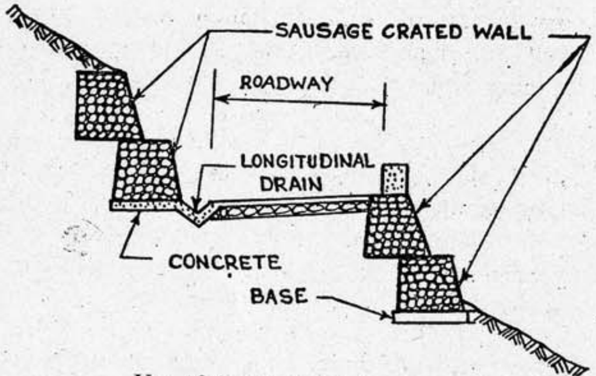
The Authors in their Paper have covered three types of retaining walls for hill roads, *viz.* :

(i) Dry Rubble Masonry walls (DRM),

(ii) Dry Rubble Masonry with cement rubble masonry bands, and

(iii) Cement Rubble Masonry Wall.

Cement concrete walls are also used in hill roads. In West Bengal another type of retaining wall which is known as crated sausage wall is extensively used, as shown below.



Use of Sausage Crated Boulder Walls as Retaining Wall in Hill Roads

The Authors have expressed doubts in para 7 (ii) at page 313 over the quality of supervision on construction works. This defective construction has also been noted by the Authors as indicated by them in Figure 6 (a) and in Photo 5. The most notable defect found in such construction is dumping of stone instead of proper bonding, resulting in improper section of the retaining wall which is the main cause of the failure of the wall. It is felt that the DRM walls are more susceptible to failure on account of such lapses.

The retaining walls founded on rocks with outward dip shall be anchored into the rock by mild steel anchor bars. Stepping of the foundation inwards might also help the stability of the walls.

Water from *jhora* passing through cross-drainage such as cause-way or culvert might affect the toe of the *khad*-side walls. Therefore, proper training of the *jhora* should be done so that water may not move sideways, thereby, affecting the stability of the wall. The toe of the walls should also be protected with crated boulders of cement masonry blocks.

Shri Dilip Bhattacharya

In the construction of hill roads in Sikkim, Bhutan and other hilly regions, the use of dry stone retaining wall with vertical and horizontal bands are very common. In Bhutan and other hilly regions, it had been experienced that due to improper bondage of the dry stone without any adhesive material as well as the scanty points of contact between adjacent two-stone blocks, due to unevenness in their surface, yielding occurred with the heavy dead-loads transferred through these few elevated points and wall is susceptible to collapse. Hence with a slightest imbalance in pressure, the retaining wall collapses. These situations create havoc specially at continuous hair-pin bends. (Ex-Sorchen hair-pin bend on Phuntoshilling-Thimphu Road).

It has also been suggested therein, that even 10 m height retaining walls may be quite safe with hand-packed selected dry stone having bedding planes tilted inwards and with drainage channel, etc. But in regions with high intensity of rains like Meghalaya and Nagaland areas with every possibility of up-hill land-slide and presence of enormous water pressure due to constant rain and uprooting of trees, etc. the dry type of wall will have more chances of getting bulged at different sections, resulting in early failures.

Recently, I had visited the Garo Hill area of Meghalaya where dry stone type of wall had proved a failure due to considerable settlements of soil and Ministry of Transport had advocated for the R. C. C. retaining walls with stone filling in-between the members. The Authors are requested to visit the spot and examine the situation.

While introducing the Paper, Mr. Gupta referred to the name of Mr. Zutshi, C. E., U. P. P. W. D. who was also in Bhutan with me and there mostly we had used the random stone rubble dry masonry in between the framework of horizontal and vertical stone masonry in proper order. Precast bands have also been used there.

Provision of R. C. C. tie member or M. S. tie bar as suggested is an old practice and rather an uneconomical one. The Authors suggestion for these type of ties needs to be substantiated by field data and costs.

Points relating to the hill-side drainage, causeways, weep-holes, back-fill soil, angle of repose of the retained soil, as well as thrust from the hills, the sunny or shaded face of the hill, presence of nearby water sources, permeability of the neighbouring soil, etc. also need to be emphasised.

Shri K. Ramulu

One cannot but agree with the Authors that the strength of the masonry is hardly ever a criterion for the stability of these retaining walls and only the integrity of the construction is of utmost importance. But in my view, the integrity of a dry-masonry retaining wall is not fully achieved by the bonding elements alone as suggested by the Authors. If one observes carefully as the mason proceeds up, the packing of the stones increases as also the use of small size stones leading to defective inter-locking in these retaining walls. The provision of horizontal bands with mortar of about 2 feet thick aids in proper packing of the stones immediately over the bands.

If the dry masonry walls are standing as good as those where bands are used, it might have been due to the fact that a more regular shaped rectangular blocks were available for construction. But in a hill road project where most of the rock material is obtained from blasting, it is difficult to find rectangular blocks. Any attempt to dress them to regular shape is going to be uneconomical.

Shri G. K. Deshpande

Dry rubble walls described in this Paper as being stable will require even superior workmanship to the ones constructed in cement mortar, by way of proper dressing of stones, better stone-to-stone contact reduction of joint thickness and

careful placement. Looking to the availability of highly skilled masons on a job, decision will have to be taken whether such a practice may be chosen in lieu of the conventional ones. Adopting it universally, may not be desirable. The savings predicted by the Authors in dry construction of the order of 3 to 10 times appears to be on a higher side. In my opinion, about 50 per cent, however, can be easily effected.

Retaining walls on valley side require extension of the road with parapets for protection of traffic. The seepage of water from road surface into the back-fill, a hazard can be avoided by asphalting the shoulders along with carriageway and providing suitable outlets through the parapets. In case of breast walls, the recommendation made by the Authors can be implemented.

The Authors have suggested special precast bonding elements of R. C. C. I feel that use of through stones in the form of lines of overlapping headers incorporated in our specifications, will serve the same purpose. If the headers however are not available, such bonding elements may be used.

Proper construction of coping or the topmost layer is important. Coping should be in dressed heavy stones. If their placement in cement mortar is not possible, I suggest the use of asphaltic mortar, *i.e.*, a mix of asphalt and sand for the sake of integrity. This will seal the joints properly and prevent ingress of water into the body of the wall and protect the lower layers from disturbance by urchins.

Shri R. G. Sawant

The Authors' suggestion to provide camber continued over the retaining wall top, for allowing the water to drain off from the road surface needs re-consideration. The water collected and drained on side shoulders will have to be prevented from entering the back-fill. This can be done by providing impervious thin bituminous layer. The water will have to be collected and drained separately away from the retaining wall.

Weep holes may be provided with A. C. pipes of 100 to 150 mm diameter or P. V. C. Pipes. This is quicker and uniform section can be obtained.

The retaining wall of boulders has less stability against sliding. This may be further studied and experimented before arriving at firm conclusions.

Shri D. H. Deshmukh

In heavy rainfall areas with erodible foundation strata, the bottom layer of the retaining wall of 2 to 3 ft height (including the toe) should be built in cement mortar. This will force the seeping water to rise and fall gently, thus preventing erosion near the toe.

Shri A. V. Dabholkar

I would suggest that geotextiles (also called synthetic fibres) could be considered for use in the back-fill since they could effectively add to the strength of the fill by improved drainage and also the stability of the wall. Since each type of case study would be different, no generalised conclusions can be drawn.

As hill roads are also important routes, the construction work of retaining walls should not be left to non-technical staff.

Dr. B. P. Bagish

I wish to make the following points for consideration and necessary clarifications :

(1) Para 1 : The top width should normally be 50 cm. whereas 60 cm proposed does not appear to be backed by any codal mandatory provision.

(2) The provisions made in IRC : 40 require :

(i) Basic stress = 14 kg/cm².

(ii) No tensile stress.

(iii) No shear stress or 1/3 compressive stress.

(iv) At base no tension and compressive stress within safe bearing capacity.

(v) Eccentricity of resultant load 'e' should not exceed 1/4 base width in Non-seismic case and 1/3 base width in seismic case.

(vi) Resultant from toe $\not>$ 1/6 width at that section, *i.e.*, maximum eccentricity of 1/3rd the width.

(vii) Safety factor shall not be less than 1.5 in seismic case and 2 in non-seismic case.

(viii) Against sliding in non-seismic case the safety factor shall be more than 1.5.

(ix) Top width shall be 50 cm.

(x) Size and laying of stone shall be as per Cl. 404.3.3 and 404.3.4.

(xi) 'Racking' shall be as per Cl. 404.3.5.5.

On the above considerations, design criteria proposed in 2 (c) needs modification.

(3) Para 4 : From equation (5) it is illustrated that for $\theta = 0°$, ratio of 'F' and 'W' is 1.05 whereas as per Cl. 403.7.3 of IRC : 40, the ratio in non-seismic case should be more than 1.5. The value of W in Table No. 1 has to be revised so as to have a factor of safety of atleast 1.5. The reason for taking the value of μ as 0.7 has not been explained. The value of μ as per P. W. D. Code of Maharashtra is :

Soft dressed over soft	.. 0.7
Hard dressed over hard	.. 0.55
Hard over soft ..	.. 0.65

(4) Para 5 : The minimum grip in earth/rock has not been based on IRC provisions which favours 1.5 m in earth and 0.6 m in rock.

(5) Para 6 : (i) A coping of 60 cm projecting 10 cm outside should normally be provided to avoid possible slip of top layer of stone. The coping should be provided with keys in bottom layer of stone; (ii) Provision of toe to accommodate falling water is worth appreciation; (iii) Live load surcharge has not been considered. For this atleast 0.6 m earth surcharge has to be considered.

(6) Para 8 : (i) Minimum depth of embedment of 0.6 m should have been recommended; (ii) Sub-para (v) top layer of about 300 mm should be mortarred; (iii) Thickness of back-fill should not be less than 600 mm.; (iv) Details given in Sub-para (iii) & (iv) seem futile in view of Cl. 404.3.3 and Cl. 404.3.4 of IRC : 40. Only reference need be given.

(7) Para 9.2. Weep holes should be given as per "Specifications of Road and Bridge Works" and not as suggested in the article, Weep holes for retaining walls upto 3 m height are not essential.

(8) Para 10 (i) (a) should be 500 mm.

Reference about the minimum grip length is missing. A minimum grip length for different types of material should have been suggested. The slope of the hill and minimum grip length will also determine the height of the retaining wall and thereby the shape and the size.

(9) Para 10.1 : In case of rock/soft rock no toe protection is necessary.

(10) Para 10.5 : What is the basis of Author recommending the height of 6 m with egg-shaped boulders ?

Shri L. M. Verma

In Border Roads Organisation, retaining walls are constructed to gain full formation width in locations where cutting of the hill-side alone does not yield the required width or is uneconomical in comparison. The specifications generally adopted is random rubble masonry (dry) upto 4 metres height. For walls more than 4 metres height, dry random masonry is provided with bands in cement mortar of 0.4 metre width and 3 to 4 metres apart both horizontally and vertically. At many locations walls have collapsed particularly during monsoons the principal cause being ingress of excessive water in the back-fill causing excessive back pressure. In such situations, whether the walls are in dry masonry or bonded masonry has not mattered at all. Providing bands in cement mortar has been found to be of little help. I fully agree that using cement mortar in retaining walls of random rubble masonry is a waste of cement and sand and more so in situations where adequate curing cannot be assured. In my experience, I have found that the stability of retaining walls, assuming that the design is adequate, lies in giving equal importance to the construction technique of (a) the wall itself; (b) the back-fill; and (c) the drainage. Dry walls constructed in the following manner have stood well all over the Himalayan belt from Jammu & Kashmir to Arunachal Pradesh and in the North Eastern States.

Construction techniques to be noted in particular are :

(a) **Wall**—Stones placed parallel to bed with its long side going inwards, (*i.e.*, towards the back-fill), one header or through stone at every 2 m in each layer, thickness of any layer equal to or less than the layer below and in no case more than the layer below, interstices filled closely by hand-packing keeping voids to minimum, weep holes sloping outwards above every header in alternate layers and breaking of joints, *i.e.*, vertical joints one over the other in alternative layers.

(b) **Back-fill**—To proceed simultaneously with the construction of wall. In rocky region, where stone is used as a back-fill material, it should be laid as closely as possible and should not exceed 50 cm per layer. Non-cohesive soil/sandy loam may be spread over each layer, sprinkled with water and compacted by a one or two tonne hand roller. The compaction should be 95 per cent in all layers except the top layer where it should be 100 per cent. If a non-plastic soil is used as a back-fill material, it should be laid in layers not exceeding 20 cm thick. It should be sprinkled with water and compacted by a hand roller, the degree of compaction obtained being 95 per cent in each layer and 100 per cent for the top layer. The laying and compaction of back-fill in the above manner is very important. Such a dense and compacted back-fill offers complete protection to the wall from the onslaught of excess back pressure caused by percolation of run-off water or sub-soil water.

(c) **Drainage**—Side drains in the hill-side are very essential and it should preferably be paved. A careful study of the water course during the first monsoon should enlighten the Engineer-in-charge about the correctness of the locations of the cross-drainage works. It is important that the cross-drainage works are completed without any delay. It is also important to ensure that the berms slope outwards and no water is allowed to stand over the back-fill portion.

The Authors have suggested in para 7 (i) of their Paper that the construction of retaining walls and breast walls should be taken up after allowing one rainy season after hill cutting. This is seldom possible where roads are constructed to meet the operational requirements of the defence forces. Breast walls are constructed after dressing up the hill-sides and in case of retaining walls, the consolidation of back-fill is of paramount importance both for the stability of the retaining walls as well as to prevent subsidences in the road formation. It is a well-known fact that Himalayan ranges are comparatively young, geologically speaking, and even after two decades of our cutting the road, the hill-sides are unstable.

The function of the headers in the construction of retaining walls is to ensure integral action both horizontally and vertically. The Authors may kindly clarify if the bonding elements suggested by them would be required in addition to the headers.

Dr. A. S. Arya and Shri V. P. Gupta (*Replies by the Authors*)

We express appreciation to the Chairman, Co-chairman and the various discussers for taking pains in reading the Paper and making valuable comments. The points raised in the discussions are clarified to the extent possible, as under.

On the **Chairman's** remark that the Paper deals with one set of conditions and certain parameters, we wish to clarify that it deals with almost all conditions of rock, soil, slope, weather, and size and shape of available stones. Moreover, various probable forces are considered along with ways to achieve safety and economy, making the findings applicable universally.

Shri Bansal has stated that the cost of dry masonry is about half of those with band and 1/3 of fully mortarred masonry. In Almora, rates per cubic metre at a given site are Rs 40.00 for dry masonry, Rs 105.00 for masonry with band, Rs 170.00 for fully mortarred, the ratio being 1 : 2.6 : 4.3. The site is 3 chain leads from 10 km of metalled road

lead. In case of interiors, the cost of cement and sand shall become even higher.

Stone masonry retaining walls on hill roads are of gravity type. Mortarred masonry wall section shall behave as one unit provided mortar is properly laid, cured and fully filled-up in joints. Dry walls consist of mass of stones which are inter-locked through friction. Constructed with care as explained in the Paper, they shall also fail in sliding only when all the stones from back to front shall move altogether, since any stone cannot move separately. Hence strength of all types of walls shall be the same as explained in para 3 of the Paper. As such, 1 : 4 : 8 concrete band is not required both practically and theoretically and as observed in practice. Before 1940, dry walls were only constructed and were quite successful. The same is recommended in Roorkee Treatise on Civil Engineering, published in 1907 and 1920 : I. R. C. Paper No. 257 of 1967 ' Construction of a Ghat Road from Bodinayakanur to Bodimettu ' also mentions that walls of height upto 15 m were constructed in dry stone masonry with success.

Shri Saxena has made a number of points which dealt with as follows :

(i) Any wall of usual dimensions whether dry or mortarred may not be able to stand back pressures caused by soil, water and live load surcharge if all the loads act together. Particularly if the back fill consists of improper filling with earth, in which case live load surcharge will also be excessive. But realistically wall of height '*h*' gets a pressure from *h*/2 to *h*/3 of high rock-fill as shown in Fig. 6 (a) to (d), since depth of wall gets increased to reach a proper base. Retaining walls constructed as shown in Figs. 6 (c) and (d) may not get any appreciable back pressure since stone-fill shall transmit vehicle load vertically on original hill face and will cause only minor surcharge. It may also be noticed that full Coulomb Wedge shall not develop, hence only partial pressures will be caused. The design load considered in the Paper is already conservative and may never act on the wall if proper drainage is maintained.

(ii) In para 11, R. C. C. bonding element has been recommended to be used below 4 m from top in tall walls, so as to provide inter-locking of stones to compensate for bad quality of masonry by improper stone placement and to ensure proper slope of masonry layers as explained in the Paper. These elements should be roughened as indicated there. Recommended projection is only 75 mm and that too below 4 m from top at 1 m centre to centre. So, climbing on wall by help of these seems improbable. These elements shall increase wall frictions with back mass as well, which should reduce the back-pressure.

(iii) Provision of scupper-type drainage holes shall relieve hydrostatic pressure fully and further it shall not be liable for choking. It shall be easy to inspect and clean in future. Most important point for these scuppers is that it shall force the masons to do good quality of masonry alround the holes. As such, it would provide automatic quality control. It will also not allow for reduction of section around it, since width of retaining can be measured after completion of wall, which is otherwise impossible. It has actually been found useful by us on many roads. It may be thought that big drainage holes may reduce the strength of wall, but indeed it is a fact that loss of strength is negligible while the benefits are immense. Provision of P. V. C. is not practicable on such a large number of walls, and it may be very costly.

(iv) Provision of toe walls shall serve the purposes as explained in the Paper. Even if any damage occurs to the toe wall, the retaining wall will remain intact. If repair of toe wall is done in time, it shall prevent complete collapse of walls in any sort of soil. Provision of stone pitching as suggested by **Shri Saxena** shall increase the cost and may therefore be used where site condition may specifically require.

Shri Sankaran stated that use of R. C. C. ties of suitable spacings has been a well-known past practice. No reference is however cited. Nor one seems available in the literature. Same is true of 20 to 25 mm diameter bars. If R. C. C. bonding elements if used should provide much economy, better quality, and higher strength of the retaining walls as given in Para 12 of the Paper. Cost analysis of 10 m high and 10 m long walls on rates prevalent in Almora, U. P. P. W. D. show that dry stone masonry wall with specified R. C. C. bonding elements will cost Rs 9,900, usual walls with bands Rs 23,800 and a fully mortarred wall Rs 38,500. The estimate of Shri Sankaran seems quite unrealistic for hill areas.

Further, if such R. C. C. pre-cast bonding elements cannot be made, carted and used at site, how carriage of bags

of cement, sand fetching and providing of required water will be possible? Carting of the R. C. C. elements should be much simpler, so also their casting at the Divisional or Sub-divisional headquarters.

We do not deny the adhesion and bond created by cement mortar in masonry of any type. The objection against its use in hill retaining walls is due to the fact that quality of construction needed to obtain this benefit is usually not possible, hence it becomes wasteful. Moreover, for the reasons given in the Paper, it is not needed too. The requirements and conditions for walls in buildings are quite different and the comparison is misplaced.

Shri Rama Rao has suggested use of clay for water-proofing of upper shoulder. Carriage of clay, its mixing with ordinary soil may be done, but practically it is difficult, costly and time-consuming. When stone spalls and soil mass are abundantly available, these may be used economically as it will serve the required purpose.

Road surface including shoulders have to be given required camber and the same has been recommended on top of retaining walls and on which parapets, edge stone can easily be constructed as done currently also. Certainly, there is great harm if road surface is given slope towards hill-side because of many reasons : Firstly, rain water shall flow on road surface from outer end to hill-side drain and try to concentrate along road length because of longitudinal slope of road. This may scour the loose mass of road surface and subsequently may damage the road crust too. Secondly, cross-flowing water may cause ruts in unmetalled road surface.

Shri Marya has cited a number of alternative types of walls such as soil cement blocks, wire crated masonry, etc. Surely they can be used in some locations where situation is favourable for them. But not in replacement of dry stone masonry where proper stone is available locally.

It is rightly said that when enough base width is not available for retaining wall in steep rocky zones, then base may be stepped and masonry anchored to the hill-side.

As suggested by **Shri S. C. Gupta**, ballies and bamboos may positively be used but they decay completely in 4 to 5 years and become totally useless. Treated wood may be used as per site situations. R. C. C. members are not very costly as explained earlier and durable too. Even these may be avoided if stones of good quality, shape and size are available.

Contrary to the fear expressed by **Shri Guram**, the assumption that the dry walls shall act as one unit is perfectly correct so long as vertical joints are broken by overlapping of stones. If stones are not so laid but dumped in the body of the retaining wall, problems may arise. Since this may be the tendency in the thicker base of taller walls, the bonding elements have been suggested as a positive means of achieving frictional bond.

The other observation is not correct because frictional resistance does not depend on area of contact but on weight of overlying stones and the co-efficient of friction between stones. There is no danger of stone crushing in 10 to 15 m high walls. It may occur only in rock-fill dams of more than 150 m height.

As regards **Shri Sodhi's** views on the concept of the bonding elements to be provided from back to front, we wish to mention that if overlapping stones could be used properly, the bonding elements may not be needed at all. But the situation at most sites is very different and 60 cm long stones are hardly seen. The usefulness of scuppers over small drains has already been explained, so also the points raised by **Shri O. P. Gupta.**

Shri Mane has given further information about adoption and some favourable facts for dry walls which is appreciated. Stepping at base near heel may be done as per details given in the Paper. Front vertical faced retaining walls can positively be adopted as suggested by Shri Mane and to details given in ' Indian Highways, ' Vol. 10, No. 3 of March, 1982.

About observation (a), the Paper seems to have been misunderstood, since it is stated to be across the length in para 8

(iii). Joints can be inter-locked by this also. Header stretcher arrangement may be followed as shown in Fig. 6 (d). For observation (b), para (iii) has again been misunderstood. In case of random rubble dry stone masonry which has to be adopted for hill roads, there is no need for levelling of any bedding plane by soil. It may be zig-zag with one aim only to result in good inter-locked mass. Stone spalls, granular mass, sandy soil be filled in stone gaps only. Clarifications of observation (c) to (g) have already been given earlier.

Regarding **Shri Tambe's** comment, we wish to inform that the slip of soil below base has been taken in paras 9.4 and 10 of Paper by providing suitable toe walls. Example given on pages 305 and 306 are for gravity walls, and the values of *Ca* and *Cas* are correctly given in Table 4. ' λ ' not printed on page 302 is a printing omission. Recommendations on page 313 are to achieve economy and assess the real requirement of retaining walls, etc. A short-cut procedure may be adopted where it is absolutely necessary but it may cause collapse even of good constructed wall due to base failure. Filter is not required behind the wall since clayey or silty soil should never be filled in back of wall.

Shri Desai has made useful comments and the live load surcharge may assume importance in soil back-fills as explained in discussions above. Including seismicity, the earth pressure calculations have been done as per IS : 1893 - 1975. The base projection by the toe wall shall be helpful at base and section just above toe wall should naturally be checked for stability. Walls with bands of cement mortar have been amply discussed in the replies above and needs no further clarification.

With reference to the comments of **Shri K. C. Bansal,** it may be stated that a structure has to be designed based on theoretical analysis as well as study of its behaviour in the past, and then from an engineering point of view, economical specifications must be adopted. The solution of dry masonry walls is based on this total approach.

Suggestions in para 7 of Paper are for both retaining as well as breast walls. The fact may be verified on newly constructed roads where retaining wall had been built just after hill cutting and got damaged soon thereafter specially in Himalayan hills. It is also seen that no road has practically been constructed fully even for one km len th in one year due to various reasons and several km long sections of roads remain idle due to delays involved in construction of bridges and culverts. Therefore postponement of wall construction can easily be adjusted in period of construction if properly planned in a phased manner.

The bonding elements should preferably be used in single pieces from back to front. Where felt necessary they may be made in 1.5 to 2.0 m lengths and overlaps provided between them by 40 to 50 cm.

Replies for various observations made by **Shri Rakshit** have been given earlier. The bonding elements as suggested in the Paper will take care of some of the common defects of poor quality constructions of DRM. Whereas crating is considered a good alternative, stepped construction of walls as shown by the discusser may not be feasible in all situations.

Most points raised by **Shri Bhattacharya** have already been discussed above. The use of properly constructed scuppers in heavy rainfall areas should be specifically useful rather than blocking the passage by R. C. bands. If use of R. C. bonding elements was an old practice, the discusser could have thrown light on their field behaviour.

We agree with **Shri Ramulu** regarding the usefulness of 2 ft thick mortarred band only if their proper construction and curing could be ensured; but can it be? Since the answer in a very large majority of cases will be in the negative, the provision of pre-cast bonding elements will be most effective.

We do not share the views of **Shri Deshpande,** that DRM will require better dressing of stones. What will actually be needed is better hand-packing and proper orientation of stones. Since in most sites, proper header stones are found missing, the use of bonding elements has been suggested.

The suggestion of **Shri Sawant** regarding weep holes provided by A. C. or P. V. C. pipes shall be very costly and not so useful since these cannot be easily cleaned when choked.

The base of 2 ft thickness in cement mortar as suggested by **Shri Deshmukh** is very costly and impractical at most sites due to difficulties in carrying out R. C. C. work.

Suggestion for use of geo-textiles by **Shri Dabholkar** is unnecessary in the context of back-fills of hill retaining walls where stone is easily available.

Dr. Bagish has supplemented the Paper with a good amount of data, useful to the readers. The points raised by him are clarified below :

(i) 0.6 m top width has been adopted because it is the most prevalent. It is also given in the current specification followed in hill road construction by U. P. P. W. D., D. G. B. R., etc. There is no objection to the use of 50 cm width.

(ii) The criterion 2 (c) is based on IS : 1893–1975. A higher factor as given by IRC though safer is unnecessary.

(iii) The value 1.05 in Eq. (5) is not the recommended value but just to show what can happen and what can be changed easily by the construction as given in Eq. (4). The same thing is explained in Table 1. For undressed or semi-dressed stones as normally used in hill walls, $\mu = 0.7$ is rather conservative.

Recommendation about size and shape of wall may be modified judiciously, conservatively as per site requirements or other criteria.

The discusser seems to be tied to one set of specifications. The aim of the Paper is to study the problem. The basis of construction of 6 m high wall with egg-shaped stones, it firstly fulfils all stability criteria and secondly, if has been quite successful on many roads since many decades in dry masonry.

The comments of **Shri Shonthu** support the main points of the Paper and in a way recommend the use of DRM with some form of bonding elements where found necessary.

Finally, we wish that the various Departments of the Central and State Governments, consider adopting the recommendations contained in the Paper for DRM with R. C. bond beams in their works atleast on an experimental basis on sufficiently large-scale so as to bring out their strong as well as weak points, if any.

Shri G. M. Shonthu (*Co-Chairman's Remarks*)

The construction of dry retaining walls are definitely much better than the pucca retaining walls. But the question is whether we are constructing them according to a proper design. I have seen, that sometimes a proper section of the retaining wall is not being dealt, instead just a face stone and a filler behind the stone is treated and you know the result. As regards the bond stone, we are just losing this practice in our retaining walls. Another point is about the back-fill and the stones not being properly compacted and put in proper layers. Mostly the stones are being dumped just behind the retaining walls. In far-flung areas where the mortar or other material is not available for providing the pucca bands, I think it is a good suggestion to use bamboo-matting and crating. This has been tried and has proved really very well. As **Shri Marya** pointed out, stone-crated walls cannot be the answer for all retaining walls, but only for specific problems.

Shri L. B. Chhetri (*Concluding Remarks of the Co-Chairman*)

In our road making, retaining walls are used for retaining the slopes as well as the formation. The retaining wall for formation gets less pressure because the water is drained by providing surfacing and drainage towards the hill-side. For the retaining of slopes, the breast wall remains moistened in most mountainous areas where the rainfall is very high. These walls have been failing mostly and the retaining walls which retain the formation as such, normally fail under the effects of scouring. In the past, bond and through stones at three to four feet between every layer have been provided for bondage. Now-a-days to render the external face of the wall beautiful dressed stones are used which do not have the graded

side in section. As a result, the dry wall face first goes off without even the pressure. The pressures are variable for various conditions like varying soil conditions, rainfall, etc. The Authors have done a lot of study, but perhaps the results may not hold good for different conditions. They have made a specific recommendation for the bond walls. Bond walls do not tend to act as one mass. For the wall to act as one mass we provide wire-netting crates so that it becomes flexible permitting slight settlements with scouring action. We have been providing more of the sausages on the river-side where some amount of flexibility is required in the toe erosion. On the hill slope, as far as retaining is concerned, mostly walls with bands or even cement concrete walls are provided with both bands sealed. As far as their recommendations in the last para suggesting strongly that use of mortarred and stone masonry walls with bands should be discontinued in hill road retaining walls, I am finding it difficult to endorse this *in toto*. We will have to try this in the field and come back again and then take a view as these may not hold good for all the conditions—conditions which are different for different places. Whatever the amount of drainage we may provide, it is found inadequate in areas where it rains continuously for about six months. The soil is always moistened, the drainage not being effective, resulting in building up of pressures. This needs to be borne in mind and a few test cases tried before finally accepting the recommendations made in the Paper.