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Use of Appurtenances for Economic and Efficient Design of Jump-type Dissipator having Diverging Side Walls for Flumed Canal Falls

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A new type of dissipator has been developed for economic design of flumed canal falls. In the proposed design, the energy dissipation and flow transition are performed in the same unit, by providing expanding side-walls for the dissipator. Performance of such dissipators without any appurtenance is extremely poor, although it seems to be more efficient from theory of hydraulic jump in an expanding passage. Different types of appurtenances were provided for improving the performance of the dissipator. Use of bad deflector in combination with wire mesh net and end still was found to be most effective. Results obtained with and without appurtenances have been compared and the improved performance of the dissipator with appurtenances has been illustrated.

Introduction

Canal falls are often flumed for economy. In all falls, arrangements must be made for energy dissipation so that there is no erosion in the tail channel. In a normal jump-type dissipator, side walls of the dissipating structure are kept parallel so that there is no separation of flow. Thus, the flumed width ($2b$ in Fig 1) is kept constant upto the end of dissipator, length of which is governed by the length of jump. Different types of jump-type dissipators, developed by USBR[1] and others[2, 3] in which side walls are kept parallel are extremely popular. Details of such dissipators are given in IS code 4977-1968.

After dissipation of energy, the flumed section (usually rectangular) is connected to the original section of the canal by means of a transition structure, length and shape of which is governed by the extent of fluming and the sub-critical flow conditions near the entry to expansion (or exit) end of

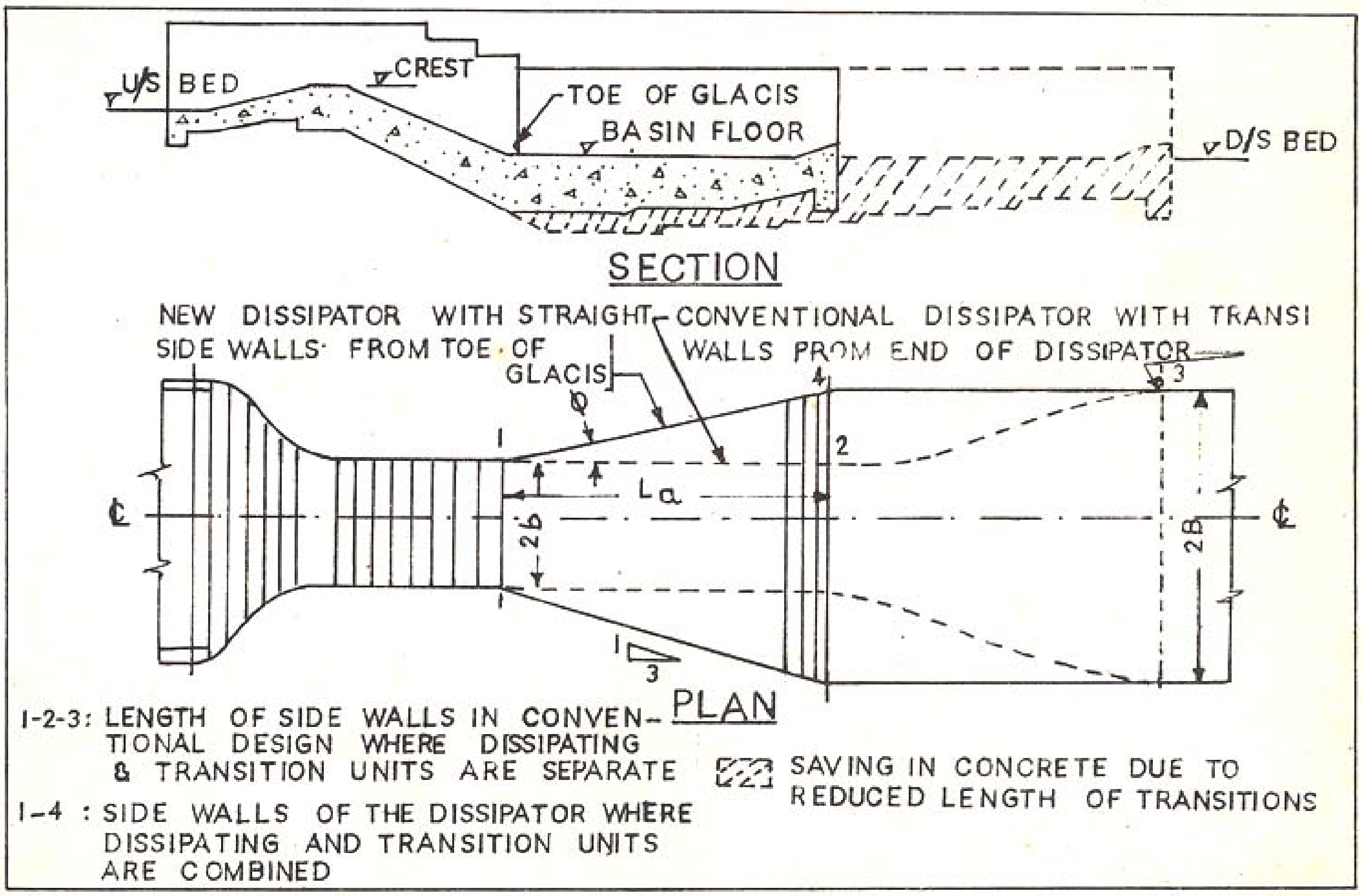

Fig 1 Conventional type and new dissipator indicating savings in concrete in floor and masonry in transition walls

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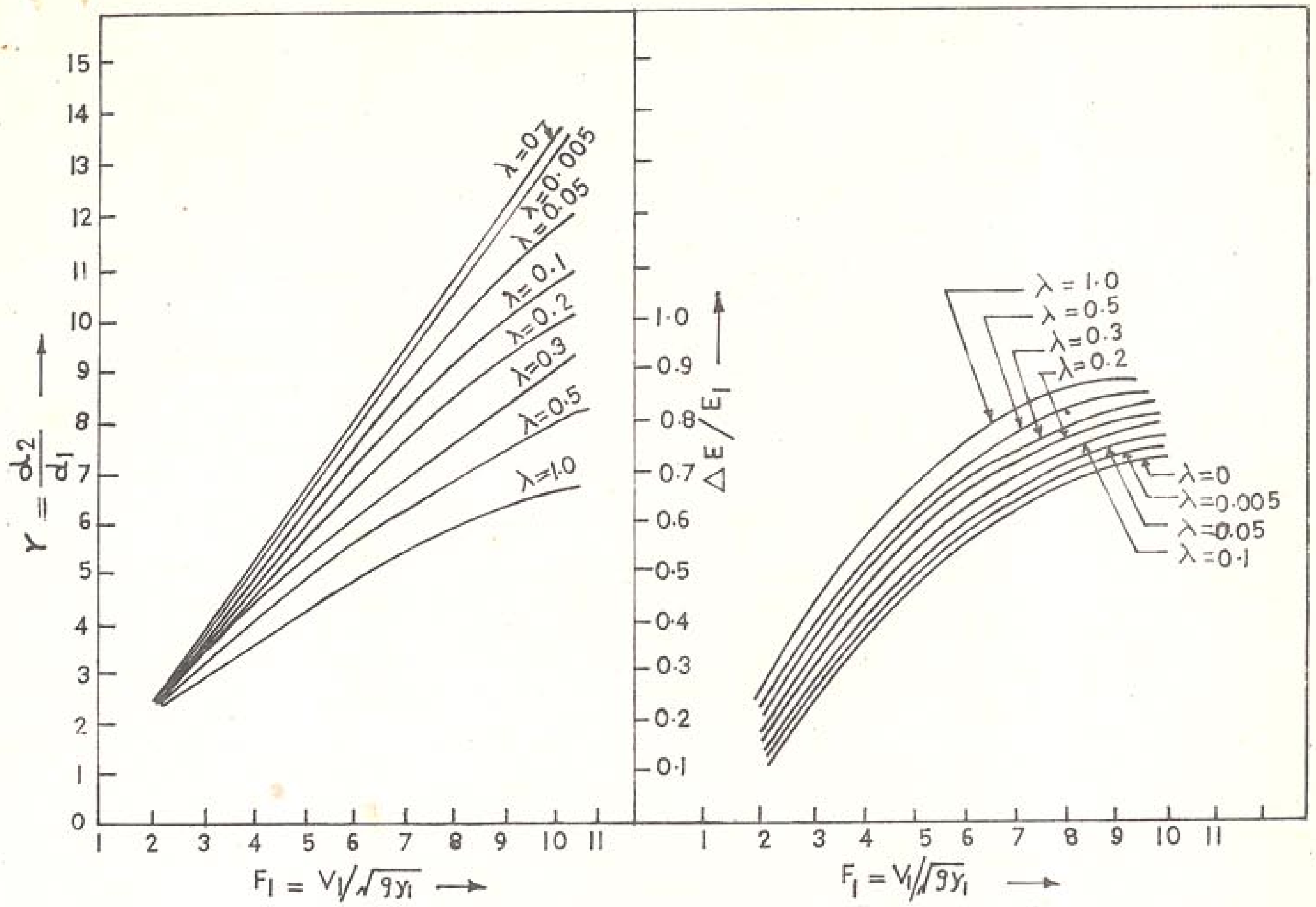
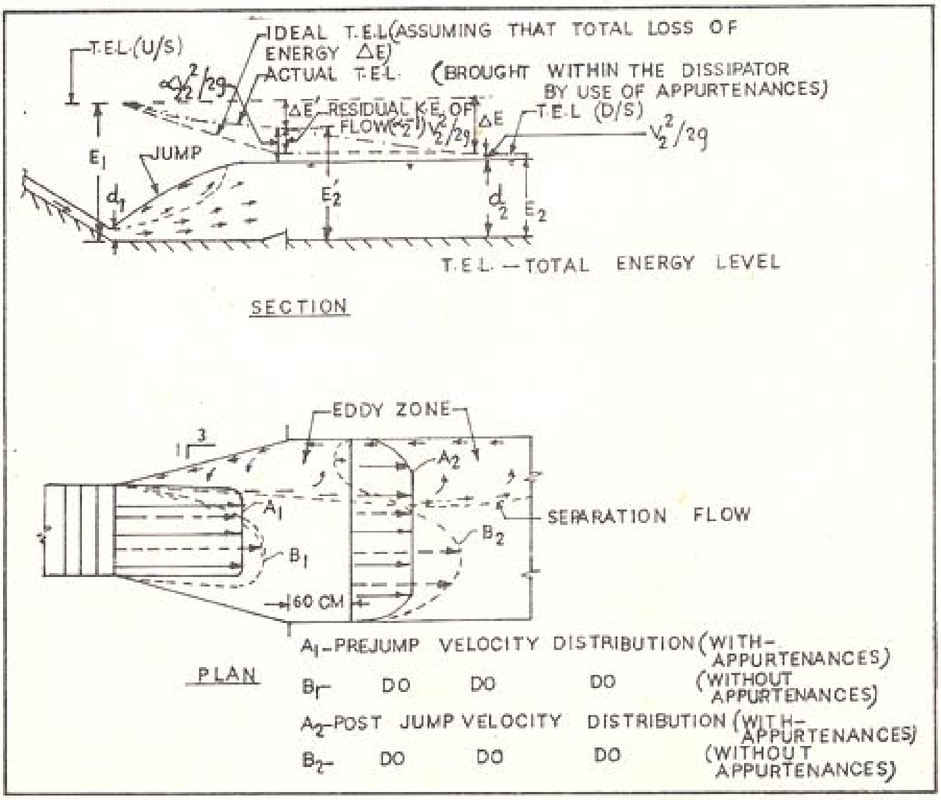


Fig 2 (a) Conjugate depth relation, and (b) Relative energy loss

dissipator. The conventional design in which the dissipating and the transition structure are made separate is extremely costly, since the entire structure, right from toe of the fall to the end of expanding transition has to be provided with a concrete floor, thickness of which will be governed by the uplift pressure. Side walls, which are very long (1-2-3, Fig 1) and have to be designed as gravity retaining walls to resist both earth pressure and seepage pressure, are also costly.

An attempt has been made to reduce the cost by developing a new type of design in which the dissipating and transition structures have been combined into one unit, by flaring the side walls (1-4, Fig 1) of the dissipating structure right from the toe of the fall. The proposed design is shown in Fig 1 by unbroken lines. The conventional type of design is indicated through dotted lines. The savings in cost due to reduced flooring (shaded area, Fig 1) and reduced length of side walls (2-3) is of substantial amount.

Fig 3 Energy loss and velocity distribution in dissipator with and without use of appurtenances



Hydraulic Jump in an Expanding Passage

Since the proposed dissipator-cum-diffuser has its side walls diverging right from toe of the fall, the hydraulic jump which forms in such diverging passage will be totally different from that occuring in the conventional prismatic type dissipator with rectangular cross-section. Theory of hydraulic jump in expanding passage has been studied by several authors, prominent amongst them being Kusnetzow[4], Unny[5], Arbhabhirama[6] and Rajaratnam. Rajaratnam's equations for conjugate depth relation ($r = d_2 / d_1$) and relative loss of energy ($\triangle E / E_1$) are:

$$1+{}^1/_3\lambda(r-1)(1+r+r^2)-[1+\lambda(r-1)]r^2=2F_1^2\left[\frac{1}{r}\left(\frac{1}{1+\lambda(r-1)}\right)-1\right] \tag{1}$$

$$\triangle E/E_1=\frac{F_1^2+2-2r-F_1^2\left[\frac{1}{r^2}\left(\frac{1}{1+(r-1)\ \lambda}\right)^2\right]}{(F_1^2+2)} \tag{2}$$

where F_1 is the pre-jump Froude's number of flow $=\frac{V_1}{\sqrt{gd_1}}$; r, the sequent depth ratio $=d_2/d_1$; d_1, d_2, the conjugate depths, before and after the jump, respectively; $\triangle E$, the ultimate loss of energy *ie* difference in reduced levels of total energy line *u/s* and *d/s* of fall (Fig 3); $\lambda=(d_1/b)(1/m)\tan\phi$; E_1 the energy of flow before jump; b, the half width of flow at flumed section before jump; ϕ, the angle of inclination of side wall with channel axis; and L_a, the axial length of the dissipator from entry to exit of expansion.

Theoretical relations given by equations (1) and (2) have been plotted in Figs 2(a) and (b). Since λ increases with ϕ, the figures demonstrate that γ value decreases with increases in ϕ, thereby indicating that such a dissipator needs less depth of tailwater (compared to conventional one in which $\phi = 0°$ and hence $\lambda = 0$). Fig 2(b) shows that the relative loss of energy is more when λ is high, *ie*, with increase in ϕ value. Such dissipators are, therefore, more effective in energy dissipation when compared to conventional ones.

Efficiency of Jump as Energy Dissipator

Conventional definition of jump efficiency (η_j) is given by the ratio of energy just after and before the jumps. η_j may be defined as (Fig 3).

$$\eta_j = E_2'/E_1 \tag{3}$$

This definition of efficiency of jump as an energy dissipator does not reflect the true performance of the dissipator. For given value of E_1, less is the loss of energy within the dissipator ($\triangle E$), more will be the residual kinetic energy of flow ($\triangle E-\triangle E'$) = $(\eta_2-1)\ V_2^2/2g$, as shown in Fig 3. Although η_j appears to be very high (since E_2 increases as $\triangle E'$ decreases), the performance of the dissipator is far from satisfactory. This is because the residual kinetic energy leaving the dissipator will bring about untold damages to the channel downstream. $\triangle E$ gives the ultimate loss in energy which has to be brought about for given levels of Total Energy Line (TEL) both u/s and d/s of the fall. If it would have been possible to bring all the losses ($\triangle E$) within the dissipator, there would have been no residual kinetic energy of flow, resulting in normal uniform flow conditions right from the end of the dissipator. In such a situation $\triangle E'=\triangle E$ and the jump efficiency is 100%. Keeping these facts in view, the efficiency of jump (η_j) as an energy dissipator has been defined as

$$\eta_j=\triangle E'/\triangle E \tag{4}$$

Performance of the dissipator has been defined in terms of η_j given by equation (5).

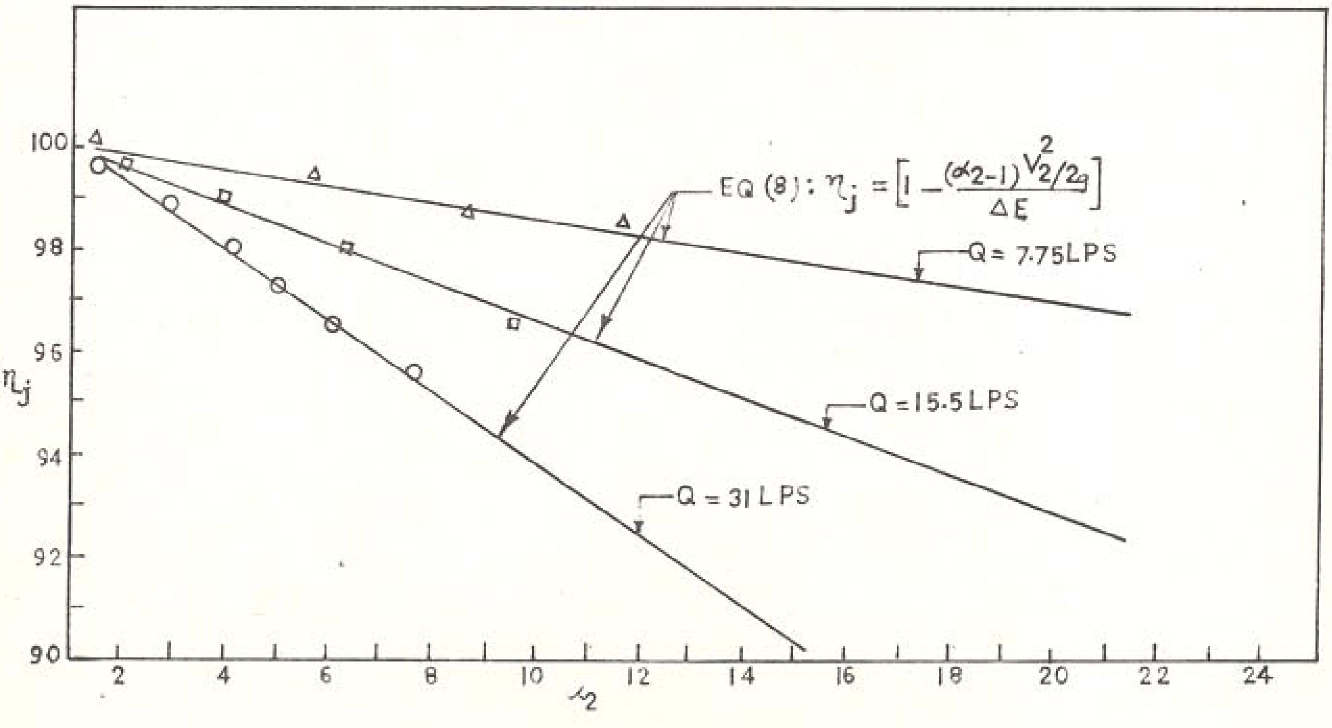
Kinetic Energy Correction Factor

The kinetic energy correction factor (α_2) may be expressed as

$$\alpha_2=\int_A u^3dA/A_2V_2^3 \tag{5}$$

Here α_2 is a measure of degree of distortion (or non-uniformity) of flow. In actual flow, $\alpha_2>1$ (normally varying from 1.10 to 1.20 for uniform flow). When α_2 is near unity, distribution of velocity is almost uniform. As shown in Fig 3, more is the residual kinetic energy of flow, higher must be the value of α_2, since a given flow at a given depth (depth of flow, d_2 and hence the mean velocity of flow, V_2, downstream

Fig 4 Variation of efficiency (η_j) with kinetic energy correction factor (α_2)



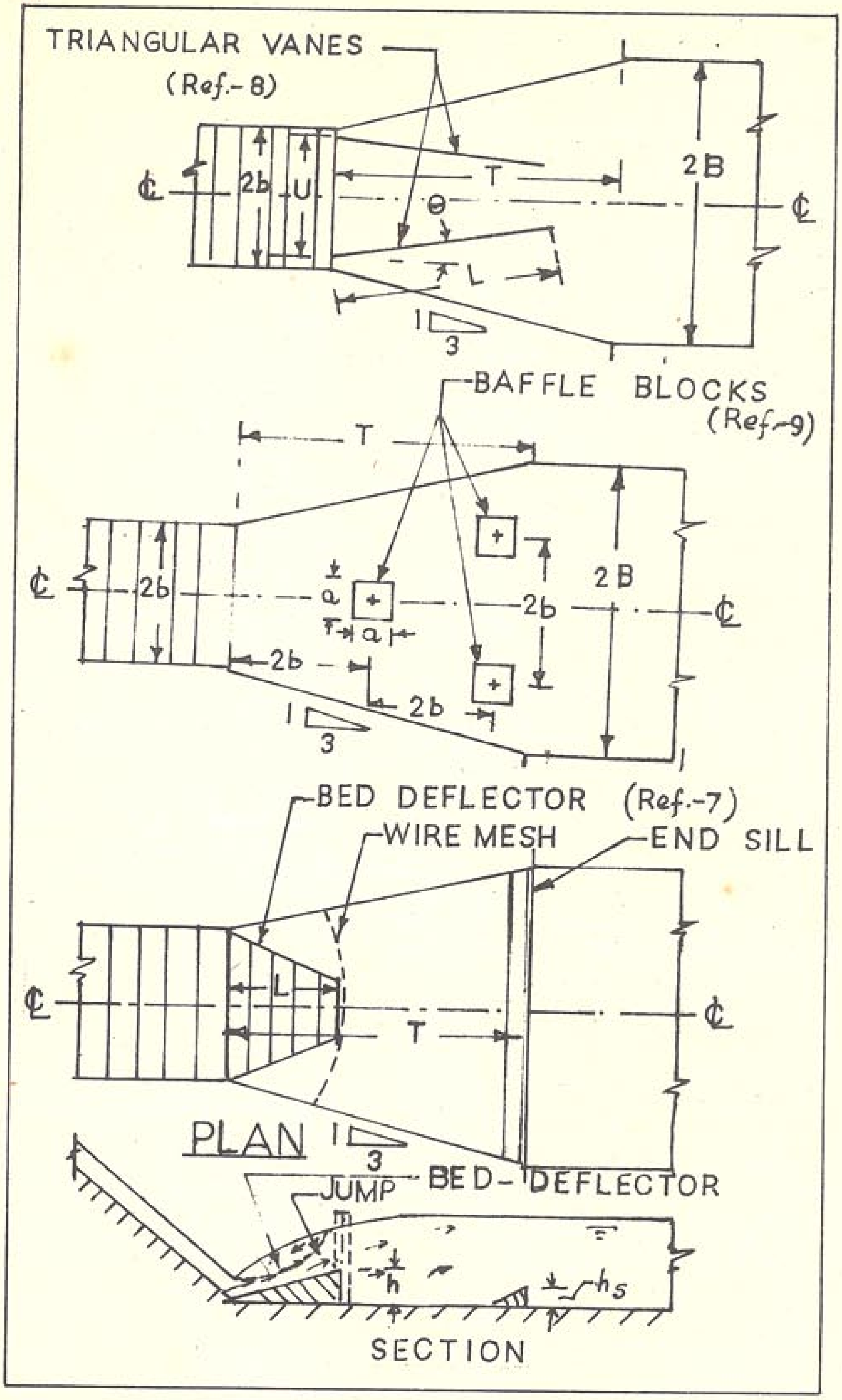


Fig 5 (a) Plan of dissipator with triangular vanes; (b) Plan of dissipator with baffle blocks; and (c) Plan and section of dissipator with bed deflector

of the dissipator remains practically constant) can contain excess kinetic energy only through distortion of flow, leading to increase in α_2 value. It is apparent from Fig 3 that the residual kinetic energy of flow leaving the dissipator is given by

$$\Delta E - \Delta E' = (\alpha_2 - 1)\, V_2^2 / 2g \qquad (6)$$

Assuming that $\alpha_2 = 1.00$ far d/s, where the flow is almost uniform. From equations (5) and (7),

$$(1 - \eta_j) = \frac{(\Delta E - \Delta E')}{\Delta E} = \frac{(\alpha_2 - 1) v_2^2/2g}{\Delta E}$$

Hence,

$$\eta_j = \frac{1 - (\alpha_2 - 1) v_2^2/2g}{E} \qquad (7)$$

For a given fall with given flow condition u/s and d/s, values of V_2 and ΔE are constant and hence equation (7) shows that higher is the value of α_2, lower is the efficiency (η_j) of the dissipator. Relation between α_2 and η_j as obtained from equation (8) is plotted in Fig 4 for different flow conditions and the measured values of α_2 and η_j are indicated in the figure.

Experiments Conducted

All experiments were conducted in the hydraulics laboratory of Delhi College of Engineering as part of M Sc (Engg) Thesis[7]. The model fall, constructed with brick masonry, was provided with a dissipator having side walls (made of aluminium sheets) diverging at a splay of 3 (axial) : 1 (lateral), as shown in Fig 1. The dissipator was tested with three different discharges, namely, Q = 31 l/sec, 15.5 l/sec and 7.75 l/sec, with corresponding prejump Froude's number of flow (F_1) being 5.15, 6.90 and 9.24, respectively. For each flow, the basin was tested under two tailwater depths, one being controlled (by d/s gate) in a way that the tailwater depth is equal to the conjugate depth d_2 and the other being the lowest depth without any d/s control. The conjugate depths (computed from equation (1) and the uncontrolled depth corresponding to different flow conditions) are given in Table 1. Velocity distributions were measured with Praudtle type pitot tube and inclined water manometer, 60 cm d/s of the end of dissipator, in order to evaluate α_2 and η_j values. Eddy zones were plotted with the help of potassium permanganate solution. Values on η_j and α_2 are given in Table 1 for different flows with and without appurtenances. Since the performance of plain dissipators was not at all satisfactory (apparent from α_2 and η_j values in Table 1 in the first six experiments, it was decided to use some suitable appurtenances for improving the performance. Various appurtenances which were tested in the subsequent experiments are briefly described.

Pair of Triangular Vanes

A pair of triangular vanes (Fig 5) were used in order to diffuse the flow and avoid separation. Such vanes have been found to be extremely efficient in expanding transition when the flow is sub-critical althrough. Length, shape, height and spacing of the vanes (made of perspex sheet) were determined from earlier work[8].

Baffles

Rectangular baffles, shown in Fig 5(b), were used as recommended by

TABLE 1 ENERGY CORRECTION FACTOR (α_2), EFFICIENCY OF JUMP (η_1) AND RELATIVE LOSS OF ENERGY ($\triangle E/E_1$) FOR DIFFERENT FLOWS (WITH AND WITHOUT APPURTENANCES)

Experiment	Discharge, sec	Tail Water depth, cm	Nature of the Appurtenances Used	α_2	$\eta = \triangle E' / \triangle E$	$\triangle E/E_1$
1	31.00[1]	9.03[2]	Without appurtenances	5.55	92.1	71.8
2	15.50[3]	6.42[4]	"	5.80	95.8	78.1
3	7.75[5]	5.47[6]	"	6.58	98.2	79.9
4	31.00	15.89[7]	"	4.08	97.8	52.2
5	15.50	11.27[8]	"	3.92	98.9	62.5
6	7.75	7.91[9]	"	9.61	98.7	71.1
7	31.00	15.89	Vanes ($L/T=0.5$, $U/2b=0.88$, $\theta=20°$)	4.14	97.8	52.2
8	31.00	15.89	Vanes ($L/T=0.5$, $U/2b=0.99$, $\theta=15°$)	4.96	97.2	52.2
9	31.00	15.89	Vanes ($L/T=0.75$, $U/2b=0.88$, $\theta=10°$)	6.04	96.5	52.2
10	31.00	15.89	Vanes ($L/T=0.75$, $U/2b=0.99$, $\theta=15°$)	6.37	96.3	52.2
11	31.00	15.89	One baffle	2.12	99.2	52.2
12	15.50	11.27	"	1.95	99.6	62.5
13	7.75	7.91	"	5.58	99.3	71.1
14	31.00	9.03	"	1.99	98.3	71.8
15	31.00	15.89	Three baffles	2.92	98.7	52.2
16	31.00	15.89	Bed deflector $L/T=0.5$, $h_s=50$ cm and end sill $h=7.5$ cm	2.43	99.0	52.2
17	31.00	15.89	Bed deflector and end sill $L/T=0.5$, $h=10.0$ cm, $h_s=5.0$ cm	2.15	99.2	52.2
18	31.00	15.89	Bed deflector with end sill and wire mesh (6 mm size) $h=10.0$ cm, $h_s=5.0$ cm, $L/T=0.33$	1.57	99.6	52.2
19	31.00	15.89	Bed deflector with end sill and wire mesh (3 mm size) $h=10.0$ cm, $h_s=5.0$ cm, $L/T=0.33$	1.38	99.7	52.6
20	31.00	15.89	Bed deflector with end sill and wire mesh (2 mm size) $h=10.0$ cm, $h_s=5.0$ cm, $L/T=0.33$	1.21	99.8	62.5
21	15.50	11.27	"	1.16	99.9	71.1
22	7.75	7.91	"	1.31	99.9	71.1
23	31.00	9.03	"	1.34	99.4	71.8
24	15.50	6.42	"	1.17	99.9	78.1
25	7.75	5.47	"	1.65	99.8	79.9
26	31.00	15.89	Bed deflector with end sill and wire mesh (2 mm size) $L/T=0.5$, $h=7.5$ cm, $h_s=5.0$ cm	1.10	99.9	62.2
27	15.50	11.27	"	1.39	99.8	62.5
28	7.75	7.91	"	1.68	99.9	71.1
29	31.00	9.03	"	1.22	99.6	71.8
30	15.50	6.42	"	1.24	99.8	78.1
31	7.75	5.47	"	1.18	99.9	79.9

Remarks

1. Full supply (FS)
2. Minimum depth without downstream control at FS
3. Half Supply (HS)
4. Minimum depth without downstream control at HS
5. Quarter Supply (QS)
6. Minimum depth without downstream control at QS
7. Conjugate depth at FS
8. Conjugate depth at HS
9. Conjugate depth at QS

For details of vanes, baffles and bed deflector refer Fig 5.

Smith[9]. Tests were made with single as well as with three baffles. Dimensions, location and spacing of the baffles were as recommended[9]. These baffles have been found to be highly effective in diffusion of flow in sub-critical expanding transitions.

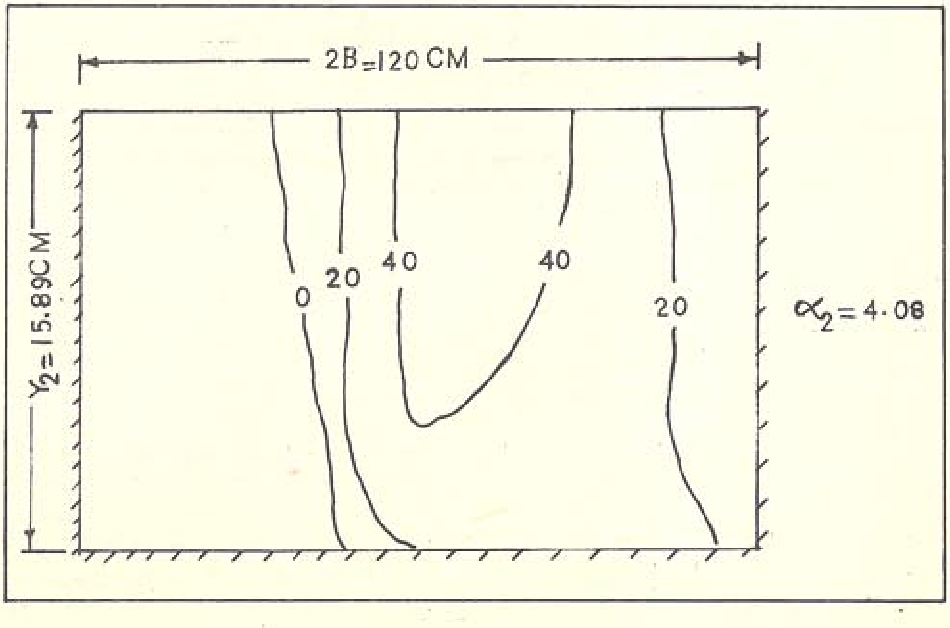
Bed Deflector

Figs 5(c) and 6 illustrate the bed deflector used. Such deflectors were used in expanding transition[10] under sub-critical flow. The shape of the deflector which was found most effective in the present case was developed by trial. Bed deflector combined with wire mesh net and end sill was found to be the most efficient.

Results

Table 1 gives the performance of the dissipator with and without appurtenances. It may be observed (experiments 1-6) that the performance of the plain dissipator without appurtenance is highly unsatisfactory under all conditions of flow. The hydraulic jump is asymmetric with large eddy on one side (Figs 3 and 7) and the live flow swinging to the other side. This resulted in a highly non-uniform distribution of velocity in the tail channel (α_2 varying from

Fig 6 Velocity distribution with appurtenance (Q = 31 LPS)



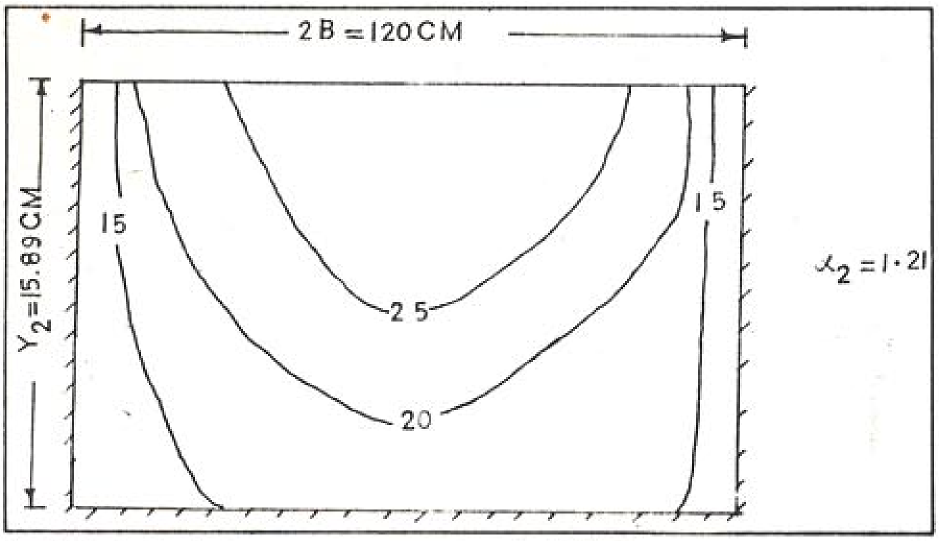
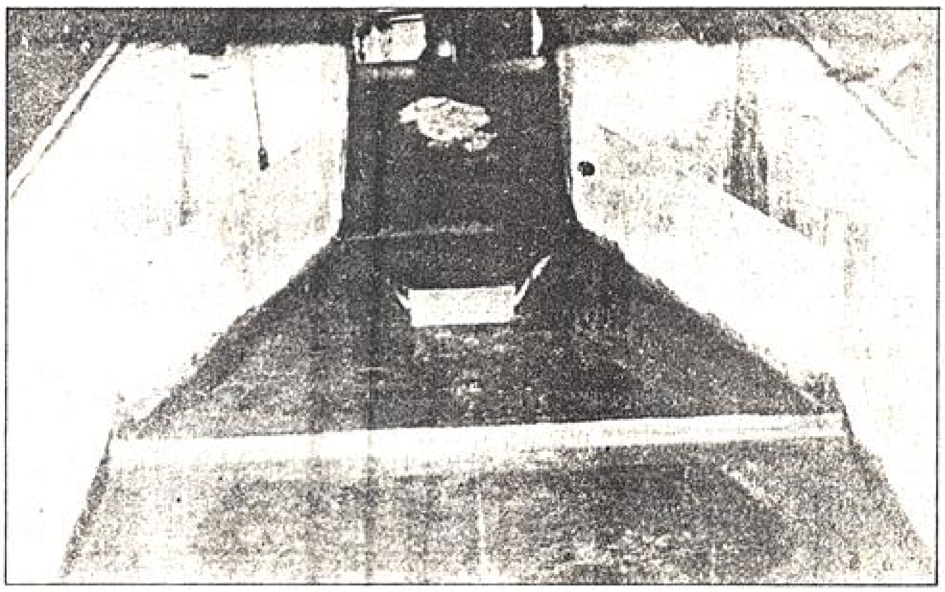


Fig 7 Velocity distribution with bed deflector (Q = 31 LPS)(L/T = 0.33, h = 10 cm, h_s = 5 cm)

5.55 to 9.61). With use of triangular vanes (experiments 7-10), there was hardly any improvement in flow conditions (α_2 varying from 4.14 to 6.37). With introduction of one baffle, (experiments 11-14) there was some improvement in flow conditions as reflected by α_2 value varying from 1.95 to 5.58. α_2 value was 2.92 when three baffles were used (experiment 15). Marked improvement in performance was obtained with introduction of bed deflectors (experiments 16 to 31). α_2 varied from 2.43 to 1.16 indicating that the flow downstream of the dissipator was almost uniform and normal, and completely free from any eddy (Figs 3 and 8). Typical distribution of velocity at a cross-section 60 cm d/s of the dissipator, plotted in Fig 9 (without bed deflector)and Fig 10 (with bed deflector) clearly demonstrates the effectiveness of bed deflector in improving the flow conditions in the tail channel. The best performance was achieved (experiment 20) with a bed-deflector (having l/t = 0.33, h = 10 cm and h_s = 5 cm as shown in Fig 5c), wire-mesh and an end sill. Jump efficiency (η_j) was 99.8%, α_2 = 1.21 and $\Delta E/E_1$ = 62.5%. The performance of the basin was almost equally good at half (Q=15.5) and quarter (Q=7.75) supply conditions, as well as with tailwater depth substantially less than the conjugate depth (experiments 23-25). Although lowest value of α_2 (=1.10) was obtained in experiment 26, the length of the bed deflector was too high (l/t = 0.5).

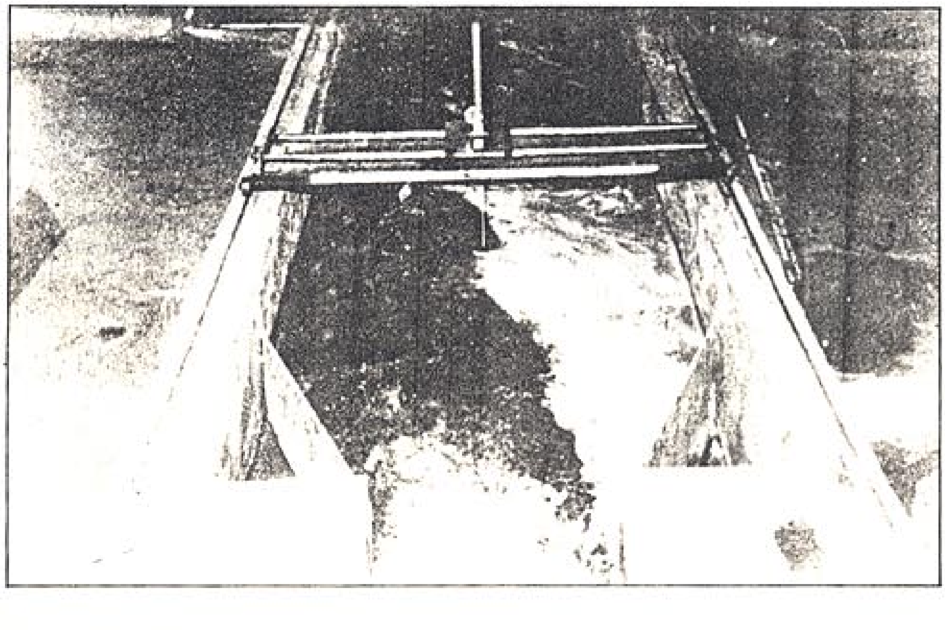
Fig 8 Dissipator provided with bed deflector and end sill



Conclusions

1. Theoretical relationship of conjugate depth and relative loss of energy for hydraulic jump in an expanding passage demonstrates that the conjugate depth (d_2) decreases and the loss ($\Delta E/E_1$) increases with increase in angle of flare (ϕ) of the diverging side walls.

Fig 9 Asymmetric jump in the dissipator without appurtenances



2. In a dissipator with diverging side walls (having 3:1 splay) the jump is asymmetric when there is no appurtenance. Performance of the dissipator is extremely poor since the flow separates from the boundary, resulting in highly non-uniform distribution of velocity in the tail-channel.

3. The root cause of separation and non-uniformity of velocity distribution is the residual kinetic energy of flow (not dissipated within the dissipator reach), leaving downstream. For a given flow, higher is the residual kinetic energy, higher will be the value of α_2 and lower will be the efficiency η_j. Theoretical relation between α_2 and η_j has also

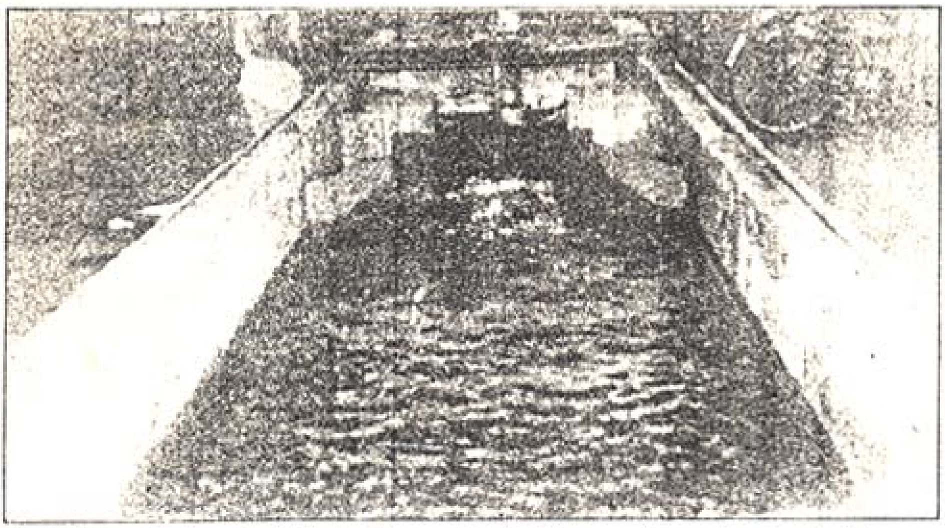


Fig 10 Symmetric jump in dissipator by use of bed deflector, wire mesh and end sill

been found to be correct by experimental observations.

4. It is possible to eliminate separation and stabilize the jump by providing suitable appurtenances. Vanes and baffles used as appurtenances did not improve the performance as much as it was when bed deflectors were used as appurtenances. The best performance (u_2 = 1.16 and η_j = 99.8%) was achieved when bed deflector (l/t = 0.33, h = 10 cm, h_s = 5 cm) was used in combination with wire mesh (2 mm size) and an end sill. The flow was completely free from any separation and was perfectly normal in the tail channel.

5. Another remarkable feature of this new type of dissipator (where the dissipating and transition structures are combined together in one unit) is that it is effective under all conditions of flow and with tail water 45% less than conjugate depth.

6. The new dissipator provided with appurtenances and diverging side walls is not only economic, it also shows better performance when compared to conventional type dissipators with parallel side walls.

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