Table 5.1 Summary of penalty parameters' settings applied to different problems constituted for various types of riprap stones

Optimization Algorithm	**Type of Riprap Stones (ϕ)**	**Objective Function**	**Manning's Roughness Coefficient for Channel Bed, n_b**	**Values of constant 'a_1' and 'a_2' in Eq. 5.5**			**Inertia weight, ω**	**Maximum Number of Iterations**	**Flow Rate and Stone Stability Constraint Equations**	**Freeboard Scenarios**
				$j = 1$	$j = 2$	$j = 3$				
Particle Swarm Optimization	Round (31.8 ^{o})	Model 1	0.025	1.410, 0.315	1.200, 0.340	1.100, 0.340	0.50-0	100	Eqs. 3.59-3.61	*Scenario 1* $f = 0$
			Using Eq. 3.35	1.410, 0.315	1.200, 0.440	1.100, 0.340	0.83-0			*Scenario 2* $f = 0.5$
	Subround and subangular (34.6 ^{o})	Model 2	0.025	1.040, 1.000	0.700, 0.434	1.660, 2.100	0.81-0			*Scenario 3* $f = 0.5\ y^{0.25}$
			Using Eq. 3.35	0.960, 1.000	0.620, 1.400	1.400, 1.250	0.80-0			
	Angular (38.4 ^{o})	Model 3	0.025	0.960, 0.760	0.760, 0.760	0.960, 0.430	0.688-0	220		*Scenario 4* $f = 0.25 + 0.25\ y^{0.25}$
			Using Eq. 3.35	0.960, 0.760	0.760, 0.760	0.960, 0.430	0.688-0			*Scenario 5* $f = 0.25 + 0.25\ y^{0.5}$

Table 5.2 Summary of the adopted ranges of decision variables

S. No.	Angle of repose, ϕ(°)	Bottom width of canal, b (m)	Depth of flow, y (m)	Canal side slope, m_1(H): 1(V)	Canal side slope, m_2(H): 1(V)	Size of riprap stone, D (m)
1	31.8	2.5-15.0	0.5-5.0	1.613-3.0	1.613-3.0	0.1-1.0
2	34.6	2.5-15.0	0.5-5.0	1.450-3.0	1.45-3.0	0.1-1.0
3	38.4	2.5-15.0	0.5-5.0	1.262-3.0	1.262-3.0	0.1-1.0

Table 5.3 Least cost canal characteristics obtained by application of Particle Swarm Optimization using round riprap stones

Column Number→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Row Number for Case I	Freeboard scenarios	Angle of Repose ϕ	Canal bottom width b	Flow depth y	Freeboad f	Side slope, m_1	Side slope, m_2	Riprap stone size D	Top Width T	Side slopes perimeter P_s	Excavated area A_t	Discharge Q	Velocity V	Froude Number, Fr	Cost of construction C	Residual *LHS of Eq. 3.47*	Residual *LHS of Eq. 3.48*	Residual $R_1+R_2+R_3$	Basis of Selection
	Case I: Clear water flow near channel bed (n_b = 0.025)																		
1	k=0 C=0 x=0	31.8	7.7399	3.0878	0.0000	1.8385	1.8385	0.1249	19.0940	12.9250	41.4290	59.9996	1.4483	0.2632	321.3464	0.0010	0.0000	0.0000	
2	k=0.5 C=0 x=0	31.8	7.7239	3.0935	0.5000	1.8306	1.8306	0.1272	20.8803	14.9915	51.3951	60.0000	1.4488	0.2630	384.8030	0.0000	0.0000	0.0000	
3	k=0 C=0.5 x=0.25	31.8	7.7239	3.0935	0.6631	1.8306	1.8306	0.1272	21.4774	15.6719	54.8495	59.9999	1.4488	0.2630	405.8179	0.0000	0.0000	0.0000	GM and MR both
4	k=0.25 C=0.25 x=0.25	31.8	7.7239	3.0935	0.5816	1.8306	1.8306	0.1272	21.1789	15.3317	53.1101	60.0000	1.4488	0.2630	395.2612	0.0000	0.0000	0.0000	
5	k=0.25 C=0.25 x=0.5	31.8	7.7239	3.0935	0.6897	1.8306	1.8306	0.1272	21.5748	15.7829	55.4221	59.9999	1.4488	0.2630	409.2831	0.0000	0.0000	0.0000	
Row Number for CaseII	**Case II: Sediment laden flow near channel bottom (n_b using Eq. 3)**																		
1	k=0 C=0 x=0	31.8	10.0292	2.6124	0.0000	1.8680	1.8680	0.1076	19.7892	11.0705	38.9490	60.1903	1.5454	0.3053	287.2650	0.0009	0.0030	0.0033	
2	k=0.5 C=0 x=0	31.8	8.3898	2.8416	0.5000	1.8272	1.8272	0.1250	20.6013	13.9208	48.4390	60.0000	1.5546	0.2945	361.7991	0.0000	0.0000	0.0000	
3	k=0 C=0.5 x=0.25	31.8	8.3898	2.8416	0.6492	1.8272	1.8272	0.1250	21.1465	14.5422	51.5528	60.0000	1.5546	0.2945	380.7424	0.0000	0.0000	0.0000	GM and MR both
4	k=0.25 C=0.25 x=0.25	31.8	8.3898	2.8416	0.5746	1.8272	1.8272	0.1250	20.8739	14.2314	49.9857	60.0000	1.5546	0.2945	371.2298	0.0000	0.0000	0.0000	
5	k=0.25 C=0.25 x=0.5	31.8	8.3993	2.8405	0.6713	1.8263	1.8263	0.1252	21.2267	14.6245	52.0204	60.0000	1.5547	0.2946	383.6724	0.0000	0.0000	0.0000	

GM: The best solution selected based on the global minimum cost; MR: The best solution obtained based on the minimum sum of all residuals ($R_1+R_2+R_3$)

Table 5.4 Least cost canal characteristics obtained by application of Particle Swarm Optimization with subround and subangular stones

Column Number →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Row Number for Case I	Freeboard scenarios	Angle of Repose ϕ	Canal bottom width b	Flow depth y	Freeboad f	Side slope, m_1	Side slope, m_2	Riprap stone size D	Top Width T	Side slopes perimeter P_s	Excavated area A_t	Discharge Q	Velocity V	Froude Number, Fr	Cost of construction C	Actual Residual *LHS of Eq. 3.47*	Actual Residual *LHS of Eq. 3.48*	Residual $R_1+R_2+R_3$	Basis of Selection
	Case I: Clear water flow near channel bed (n_b = 0.025)																		
1	k=0 C=0 x=0	34.6	8.3532	3.0396	0.0000	1.6419	1.6418	0.1156	18.3341	11.6865	40.5591	60.1421	1.4828	0.2716	290.5600	0.0037	-0.0025	0.0026	GM and MR both
2	k=0.5 C=0 x=0	34.6	8.3697	3.0335	0.5000	1.6401	1.6404	0.1157	19.9611	13.5758	50.0533	59.9933	1.4819	0.2717	345.7464	-0.0264	-0.0074	0.0015	
3	k=0 C=0.5 x=0.25	34.6	8.3697	3.0335	0.6599	1.6401	1.6404	0.1157	20.4855	14.1900	53.2863	59.9933	1.4819	0.2717	364.2377	-0.0264	-0.0074	0.0015	
4	k=0.25 C=0.25 x=0.25	34.6	8.3697	3.0335	0.5799	1.6401	1.6404	0.1157	20.2233	13.8829	51.6593	59.9933	1.4819	0.2717	354.9496	-0.0264	-0.0074	0.0015	
5	k=0.25 C=0.25 x=0.5	34.6	8.3697	3.0335	0.6854	1.6401	1.6404	0.1157	20.5694	14.2882	53.8109	59.9933	1.4819	0.2717	367.2254	-0.0264	-0.0074	0.0015	
Row Number for CaseII	**Case II: Sediment laden flow near channel bottom (n_b using Eq. 3)**																		
1	k=0 C=0 x=0	34.6	6.3596	3.2353	0.0000	1.6513	1.6513	0.1224	17.0445	12.4915	37.8596	59.9999	1.5848	0.2814	285.7810	0.0000	0.0000	0.0000	GM and MR both
2	k=0.5 C=0 x=0	34.6	6.3729	3.2318	0.5000	1.6528	1.6528	0.1219	18.7090	14.4182	46.8003	60.0001	1.5848	0.2815	339.2825	0.0000	0.0001	0.0000	
3	k=0 C=0.5 x=0.25	34.6	6.5740	3.1904	0.6682	1.6504	1.6504	0.1217	19.3107	14.8922	49.9391	59.9645	1.5875	0.2838	356.6866	0.0004	-0.0005	0.0006	
4	k=0.25 C=0.25 x=0.25	34.6	6.3729	3.2318	0.5852	1.6528	1.6528	0.1219	18.9906	14.7474	48.4062	60.0001	1.5848	0.2815	348.7931	0.0000	0.0001	0.0000	
5	k=0.25 C=0.25 x=0.5	34.6	6.5740	3.1904	0.6965	1.6504	1.6504	0.1217	19.4041	15.0015	50.4870	59.9645	1.5875	0.2838	359.9017	0.0004	-0.0005	0.0006	

Table 5.5 Least cost canal characteristics obtained by application of Particle Swarm Optimization with angular riprap stones

Column Number→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Row Number for Case I	Freeboard scenarios	Angle of Repose ϕ	Canal bottom width b	Flow depth y	Freeboad f	Side slope, m_1	Side slope, m_2	Riprap stone size D	Top Width T	Side slopes perimeter P_s	Excavated area A_t	Discharge Q	Velocity V	Froude Number, Fr	Cost of construction C	Residual *LHS of Eq. 3.47*	Residual *LHS of Eq. 3.48*	Residual $R_1+R_2+R_3$	Basis of Selection
	Case I: Clear water flow near channel bed (n_b = 0.025)																		
1	k=0 C=0 x=0	38.4	8.6154	3.0655	0.0000	1.3739	1.3739	0.1266	17.0385	10.4181	39.3207	59.9999	1.5259	0.2783	269.8180	0.0000	0.0000	0.0000	
2	k=0.5 C=0 x=0	38.4	8.6138	3.0661	0.5000	1.3730	1.3730	0.1271	18.4066	12.1148	48.1791	59.9999	1.5260	0.2783	320.0014	0.0000	0.0000	0.0000	
3	k=0 C=0.5 x=0.25	38.4	8.6138	3.0661	0.6616	1.3730	1.3730	0.1271	18.8504	12.6639	51.1901	59.9999	1.5260	0.2783	336.7488	0.0000	0.0000	0.0000	GM and MR both
4	k=0.25 C=0.25 x=0.25	38.4	8.6138	3.0661	0.5808	1.3730	1.3730	0.1271	18.6285	12.3893	49.6756	59.9999	1.5260	0.2783	328.3388	0.0000	0.0000	0.0000	
5	k=0.25 C=0.25 x=0.5	38.4	8.6138	3.0661	0.6878	1.3730	1.3730	0.1271	18.9222	12.7526	51.6835	59.9999	1.5260	0.2783	339.4830	0.0000	0.0000	0.0000	
Row Number for Case II	**Case II: Sediment laden flow near channel bottom (n_b using Eq. 3)**																		
1	k=0 C=0 x=0	38.4	6.8982	3.1960	0.0000	1.3937	1.3937	0.1260	15.8069	10.9647	36.2829	59.9999	1.6537	0.2954	256.9989	0.0000	0.0000	0.0000	
2	k=0.5 C=0 x=0	38.4	7.9983	2.9996	0.5000	1.3617	1.3617	0.1389	17.5290	11.8247	44.6677	59.9999	1.6555	0.3052	308.1187	0.0000	0.0000	0.0000	
3	k=0 C=0.5 x=0.25	38.4	8.0898	2.9843	0.6572	1.3598	1.3598	0.1397	17.9928	12.2926	47.4888	59.9999	1.6551	0.3059	324.4233	0.0000	0.0000	0.0000	GM and MR both
4	k=0.25 C=0.25 x=0.25	38.4	8.1045	2.9815	0.5785	1.3601	1.3601	0.1394	17.7886	12.0198	46.0897	59.9999	1.6550	0.3061	316.1790	0.0000	0.0000	0.0000	
5	k=0.25 C=0.25 x=0.5	38.4	8.0891	2.9844	0.6819	1.3598	1.3598	0.1397	18.0597	12.3766	47.9340	59.9999	1.6551	0.3059	326.9636	0.0000	0.0000	0.0000	

Table 5.6 Performance comparison of different riprap stones for minimum cost channel under *freeboard scenario 4*

Flow characteristics near channel bottom	**Channel features**	**Round stone** ϕ **= 31.8**	**Subround and subangular stone** ϕ **= 34.6**	**Angular stone** ϕ **= 38.4**	**Remark**	**Cost of channels riveted with angular stone under Cases I-II,** $
Clear Water (Case I)	*b* (m)	7.7239	8.3697	8.6138	-	*328.3388*
	y (m)	3.0935	3.0335	3.0661	-	
	m (-)	1.8306	1.6404	1.3730	Steepest slope for angular stone	
	V (m/s)	1.4488	1.4819	1.5260	Highest flow velocity with angular stone revetment	
	Cost ($) per meter	395.2612	354.9496	*328.3388*	Lowest cost by angular stone	
Sediment-laden flow (Case II)	*b* (m)	8.3898	6.3729	8.1045	-	*316.1790* (Lower than Case I)
	y (m)	2.8416	3.2318	2.9815	-	
	m (-)	1.8272	1.6528	1.3601	Steepest slope for angular stone	
	V (m/s)	1.5546	1.5848	1.6550	Highest flow velocity with angular stone revetment	
	Cost ($) per meter	371.2298	348.7931	*316.1790*	Lowest cost by angular stone	