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Evaluation of Rubber Dams for SHP in India

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Abstract

India is blessed with great Himalayas as well as hilly areas in peninsular and central areas providing opportunity for hydro power at all scale including Small Hydropower (SHP) development. Water is diverted from the streams for hydro power generation using suitable diversion structures. Conventional types of raised-crest weirs are not well suited for hill streams having steep slopes and boulder movement during floods. Inflatable dam or also known as rubber dam is one type of diversion structure to control and regulate the water for power generation.The experience of inflatable dams in India is very limited even though worldwide over 4,000 installations exist and more than 10 manufacturers offer this type of weir. There are only three installations so far used for irrigation or municipal purposes and not a single rubber dam for hydropower projects in India. For selecting a suitable diversion structure, economic and technical aspects are to be carefully considered. Different types of diversion weirs including rubber dam used for diverting water for Small Hydropower (SHP) projects are studied and presented. The design of diversion weir depends on the quantity of water withdrawal and width of stream. This study is an attempt to study the rubber dam technology for Small Hydropower in India. Five different sites were selected for the present study. Rubber dam was also compared with conventional raised gravity weir, trench weir (*Tyrolean*), bush and boulder weir and "*mathu bund*" (a local name). The life cycle of these different types of weirs for same hydraulic conditions and for different discharge were computed and compared with that of imported rubber dam as well as Indian rubber dam. The cost of rubber dam was estimated based on personal communications with the experts of manufacturers and practitioners of the subject area, as well as case studies of already constructed rubber dams in India installed for purposes other than hydropower. Operation and maintenance cost and different losses on account of head, water loss and repair were taken into account for different types of weirs for calculating life cycle cost. Possible damage that may be caused by major flood for different types of weir was also calculated monetarily in terms of power loss. The ease of inflation and deflation reduces the flood damage cost, O & M cost, sediment removal cost and repair work cost. With the comparative analysis, it is found that average life cycle cost of raised gravity weir, bush and boulder, *mathu bund* and trench weir (*Tyrolean*), is 2,3, 5 and 6 times respectively more than imported rubber dam. Life cycle cost of Indian rubber dam and average life cycle cost of imported rubber dam is about three times more than Indian rubber dam. It is recommended to use inflated weir in Small Hydropower projects being cost effective and energy efficient.

Keywords: Cost Effective, Inflatable Dams, Life Cycle Cost, SHP, Weir

1. Introduction

The Small Hydropower (SHP) project comprises of diversion weir, feeder channel/intake channel, desilting tank, power channel, forebay tank and penstock pipe and power house. For smaller hydroelectric power stations the choice of retaining works depends on whether the headwater needs to be kept at a constant level. These maintain a steady water level upstream of the dam and the turbine is synchronized such that this water level is maintained. In the recent past inflatable dams have been gradually more accepted and are widely used worldwide.

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In India, rubber dam is not used as weir for Small Hydropower projects.

This study is an attempt to study the rubber dam technology for Small Hydropower in India. Comparison of life cycle cost between conventional weirs and rubber dam for Small Hydropower plants is made.The design of diversion weir depends on the quantity of water withdrawal and length of weir. The different types of conventional weirs constructed to divert water for hydropower generation in small hydropower projects are Raised gravity type, Trench weir, Bush and boulder and Mathu bund.The cross section of different types of weirs is shown in Figure 1.

2. Rubber Dams

Inflatable weirs, also known as rubber dams are flexible elliptical structures made of rubberized material attached to a rigid concrete base and inflated by air, water or a combination of air/water. When they are inflated they serve as weir and when they are deflated they function as a flood mitigation device and provide automatic flushing of sediments. The simplicity and flexibility of the rubber dam structure and its proven reliability are key consideration in its wide scope of applications1.The first inflatable dam was developed in mid-1950s by an American engineer, Norman Imbertson. It was 1.52m high, 39.6m long. The product was called as "Fabridam" and was inflated by a combination of water and air. The fabric used was nylon-reinforced neoprene and was manufactured by Firestone Tire and Rubber Co. Akron, Ohio[2]. The main advantages of rubber dams are long span and adaptable to different side slopes, short construction period, easy maintenance and repair, low project life cycle cost, earthquake resistant, adaptable to adverse conditions and environmentally friendly[3].

3. Global Experience of Rubber Dams

Some researchers investigated experimentally small overflow of rubber dam and when fully-inflated rubber dam, the downstream face of the dam follows closely the

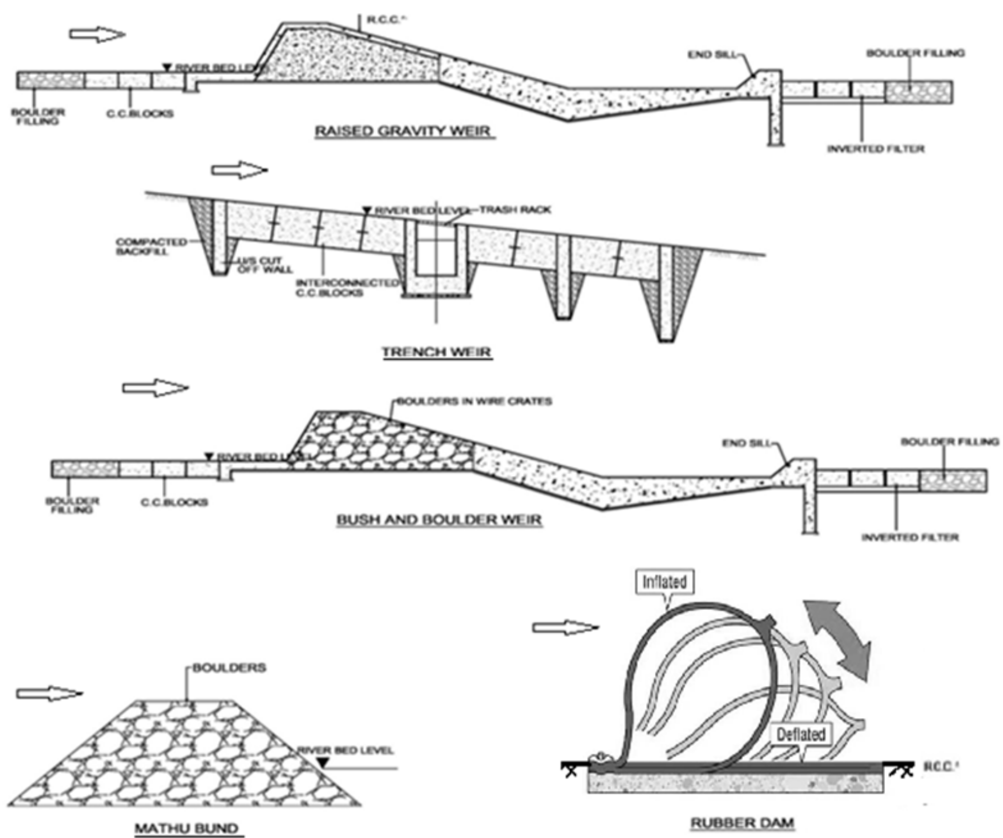

Figure 1. Different types of weirs.

shape of circular cylinder[4]. Some researchers studied effect on rubber dam[5,6]. A number of researchers considered the vibrations in inflated membrane dam[7–13]. One researcher studied use of rubber dam for flood mitigation in Hong Kong[14–18]. Moreover one more study reviewed the overflow of Inflatable Flexible Membrane Dams (IFMD) and detailed both deflated and fully-inflated configurations[17]. A dynamic simulation of the response of an inflatable dam subjected to a flood[19]. Two dimensional elastica analysis of equilibrium shapes of single anchor inflatable dams was studied by researcher[20]. U. S. Army Corps of Engineers studied performance of inflatable dams in ice-affected waters[21]. A detailed discussion on various issues related to the construction, operation, maintenance and repair of the 20 rubber dams that have been installed in Hong Kong[22]. The behavior of air or water inflated dams under different conditions of internal pressure, upstream and downstream heads of water was physically studied and analyzed[23]. The causes of vibrations and the effects of counter measures at water-filled inflatable dams were discussed[24].

4. Indian Experience of Rubber Dams

Use of inflatable weir for diverting water in hydropower projects has not been experienced in India till date even though worldwide over 4,000 installations exist and more than 10 manufacturers offer this type of weir. There were more than 2000 inflated rubber dams around the world by the year 1998[16] but the use of rubber dam as weir is a relatively new concept in India. India's first rubber dam was built in 2006 on Janjavati River. Two rubber dams on Musi River in Hyderabad, one kilometre apart, near the A.P. High Court (length 80m and height 1.35m) and at the Salar Jung Museum (length 73m and height 1.30m) were constructed under ambitious Musi Beautification Project taken up by the Greater Hyderabad Municipal Corporation (GHMC). These two rubber dams are not presently operational because of lack of pure water in Musi River. To give more flexibility in release and control of water flow across the streams in watershed management, research efforts were made at Directorate of Water Management (DWM), Bhubaneswar in collaboration with Indian Rubber Manufacturers Research Association (IRMRA), Central Institute for Research on Cotton Technology (CIRCOT) and Kusumgar Corporates Pvt. Ltd., Mumbai to design, fabricate and install rubber sheets instead of cement material for check dams and to study their impact on crop performance[25]. Table 1 below gives the details about rubber dams in India.

5. Life Cycle Cost

The Life Cycle Cost (LCC) is defined as: "It covers all the costs from project conception to final scrapping and disposal and includes all costs of operation, repairs, maintenance, energy consumption, rentals, insurance. etc, in addition to the initial costs of development and/or acquisition, all discounted to the same point in time"[26]. It covers all the costs from project conception to final scrapping and disposal and includes all costs of operation, repairs, maintenance, energy consumption, rentals, insurance etc, in addition to the initial costs of development and/or acquisition, all discounted to the same point in time. Life cycle costing is a comparative assessment of competing design alternatives based on their respective life cycle coats over their economic life

This study is an attempt to study the rubber dam technology for SHP in India. Comparison of Life Cycle Cost between conventional weirs and rubber dam for Small Hydropower plants was made.The method adopted for calculating Life Cycle Cost is Present Worth (PW) method[26]. In this method, all the costs are converted to

Table 1. Examples of rubber dams in India

Year of construction	Height (m)	Length (m)	Name of Site/Place	Mean Sea Level (m)	River	Purpose
2008	1.35	80	21.1km RD-High Court Hyderabad	150	Musi River	River Management
2008	1.30	73	22.1 KM RD-Salar Jung Museum Hyder-abad	150	Musi River	River Management
2005	3.3	2x30	Janjhavathi-Andhra Pradesh	180	Janjhavati	Irrigation

the present values. The expenditure at different periods of time have to be multiplied by Present Worth Factors (PWF) for converting to Present Worth.

Present Worth Factors (PWF) = $(1 + 0.01 \text{ x } i)^{-t}$

Where i = discount rate per annum and t = number of years.

Rate of escalation for maintenance and operating costs @ 4% per year. The effect inflation on LCC calculations will be to increase the present worth of future expenditure. The expression for Present Worth Factor (PWF) and Uniform Worth Factors (UPWF) in such cases, by taking into consideration both the discount rate (i) and escalation rate (r) for a given time period (t), may be obtained as follows:

PWF = b^t $\quad upwf = \frac{b(1- b^t)}{1- b}$

Where $\quad b = \frac{(1+ 0.01r)}{(1+ 0.01i)}$

For i = 12%, r = 4% and t= 20 years, PWF= 0.22714 and UPWF = 10.047. The present worth of amount spent every year would be product of amount and UPWF. Life cycle cost is the sum of (a) total initial cost (b) Salvage and single expenditure (c) Present worth of revenue loss due to head loss, water loss due to flushing, sediment and repair works and (d) Present worth of Annual cost (O&M).Life cycle cost was worked out for four different discharges for three hydropower projects and single value of discharge for two projects.Different projects and discharge values for finding out life cycle cost is given in Table 2.

The initial installation cost was worked out with the help of drawings for each of the project for different type of weirs and is given in Table 3.

The operational and maintenance cost for different conventional weirs, Indian rubber dam and imported rubber dam was worked out by considering cost of repair due to flood, sediment removal cost, cost of operation and repair works for a typical 2.5 cumecs of water withdrawal for Sasoma site is given at Table 4. In trench weir as water is withdrawn at the level below the bed level, the head is reduced by 1.5 m or above. Thus, generation loss due to reduced head (loss) is calculated by taking head loss as 1.5 meters for different water withdrawal values and 3 meters in case of Jhanjavati project.

Power loss (p) is calculated by using power equation and total generation loss is calculated by multiplying power loss with time.

$p = 9.81 * Q * H * \eta$

Overall efficiency (η) is assumed as 60 percent and electricity unit cost (kWh) is taken as INR (Indian Rupee) 4. In case of Trench Weir because of more sediment, it is necessary to flush some part of water back to river.

Table 2. Different projects and discharge values for finding out Life Cycle Cost

S. No	Project	Length of weir (m)	Design flood discharge (cumecs)	Discharge for Hydropower generation (cumecs).
1.	Sasoma (J&K)	18	286	2.5
3.	Zunkur (J&K)	33	175	5
2.	Umbulung(J&K)	35	382.4	10
4.	Pahalgam (J&K)	30.5	425	28.9
5.	Jhanjavati (AP)	60	1800	100

Table 3. Initial installation cost of different types of weir for five different projects

Project	Raised Gravity	Trench Weir	Bush and Bolder	*Mathu* Bund	Indian Rubber Dam	Imported Rubber Dam
Sasoma	120	118	33	28	30	115
Zunkur	227	117	54.32	60	43	180
Umbulung	270	243	252	72	68.4	59.4
Pahalgam	203.3	199.9	55.09	47.4	50.8	194.9
Jhanjavati	499.0	531.0	148.05	126.0	135.0	535.0

Table 4. Operational and maintenance cost (in INR) for different weirs for a typical 2.5 cumecs of water withdrawal

Aspects	Types of weir					
	Raised Gravity Weir	Trench Weir	Bush and Boulder Weir	*Mathu* Bund	Indian Rubber Dam	Imported Rubber Dam
Major flood damage	50,000	100,000	300,000	470,000	30,000	20,000
Sediment removal	40,000	60,000	200,000	100,000	10,000	40,000
Cost of operation	120,000	50,000	120,000	100,000	50,000	100,000
Minor damages	75,000	30,000	200,000	30,000	20,000	25,000
Repair works	80,000	150,000	200,000	300,000	40,000	20,000
Total (INR)	**365,000**	**390,000**	**1020,000**	**1000,000**	**150,000**	**205,000**

Table 5. Revenue loss due to on head loss and power loss due to water loss for flushing

Project	Discharge (Cumecs)	Trench weir					
		Head loss			water for sediment flushing		
		Head (m)	Power Loss (kW)	Cost (INRx10^5)	Head (m)	Power Loss(kW)	Cost (INRx10^5)
Sasoma	2.5	1.5	22.07	7.72	50	147.15	12.7
Zunkur	5	1.5	44.14	15.468	50	294.3	25.42
Umbulung	10	1.5	88.29	30.94	50	588.6	50.85
Pahalgam	28.9	1.5	255.15	894	50	1701.05	146.97
Jhanjavati	100	3	1765.8	618.4	50	5886	169.5

Normally 20% of discharge (Q) is normally flushed out. Time is taken as 3 months.Net head (H) is taken constant for all calculations (H=50m). Mathu Bund gets damaged due to flood and we have to repair it.

For the repair work, there is loss of discharge and hence loss in power generation. In case of every type of weir there are some losses due to repair work but in case of Mathu Bund and Bush and Boulder type this loss is more because they are damaged to greater extend. For calculation of generation loss due to repair work, extra time is taken as 20 and 10 days for "Mathu Bund" and Bush and Boulder type respectively. The revenue loss due to head loss, flushing and repair works for Sasoma site (2.5 cumecs water withdrawal),Jhanjavati and Pahalham are shown in Tables 5 and 6.

The Life Cycle Costing has been worked for a life span of 20 years, a period for which reasonable prediction could be made. Salvage/scrap value has been assumed based on the utility of the product at the end of 20 years. In case of rubber dam, rubber can be used somewhere else after the project and cost of it will add to salvage value. The discount rate is assumed as 12%.

Table 6. Revenue loss due to water loss due to repair

Project	*Mathu* Bund			B&B weir
	Head (m)	Power Loss (kW)	Cost (INRx105)	Cost (INRx105)
Sasoma	50	735.75	14.13	7.06
Zunker	50	1471.5	28.26	14.13
Umbulung	50	2943	56.52	28.26
Pahalgam	50	8505.27	163.3	81.65
Jhanjavati	50	29430	565	282.52

Present worth of different losses is worked out by assuming inflation of 4% and accordingly values are obtained by multiplying estimated cost with the present value factor. The sum of all these values for 20 years will give Net Present Worth (NPW). Calculation of Net Present Value of different revenue losses for Sasoma site (2.5 cumecs water withdrawal is shown in Table 7. The economical life and other basic data for working out the life cycle cost of six alternatives for Sasoma project is given in the Table 8. The same method was applied to calculate the present worth of each loss in different type of weirs. The result of different losses in terms of present worth is given in Table 9. Life Cycle Cost (INRx10^5)

Table 7. Net Present Worth (NPW) (INRx10^5) of different revenue losses due to head loss of trench weirfor Sasoma Project

Year	0	1	2	3	4	5	6	7	8	9	NPW
Estimated cost	7.72	8.03	8.35	8.68	9.03	9.39	9.77	10.16	10.57	10.99	83.53
Present worth	7.72	7.17	6.66	6.18	5.74	5.33	4.95	4.60	4.27	3.96	
Year	10	11	12	13	14	15	16	17	18	19	
Estimated cost	11.43	11.88	12.36	12.85	13.37	13.90	14.46	15.04	15.64	16.26	
Present worth	3.68	3.42	3.17	2.95	2.74	2.54	2.36	2.19	2.03	1.89	

Table 8. Basic data and assumptions of five projects for single discharge for working out Life Cycle Cost of different weirs

Project	Item	Raise d Gravity	Trenc h Weir	Bush and Bolder	*Mathu* Bund	Indian Rubber Dam	Imported Rubber Dam
Sasoma	Economical life (Years)	20	20	10	5	20	20
	Discount rate	12%	12%	12%	12%	12%	12%
	Total initial cost (INRx10^5)	120	118	33	28	30	115
	Operational and maintenance cost (Annual) (INRx10^5)	3.65	3.9	10.2	10	1.5	2.05
	Single expenditure at the end of 10 years (INRx10^5)	29	42	19.8	61.6	18	69
	Salvage value after 20 years (INR)					9	34.5

Table 9. Net Present Worth (NPW) (INRx10^5) of different revenue losses

Site	Trench Weir				Bush and Bolder		*Mathu* Bund	
	Loss due to head loss		Loss due to flushing of water		loss due to repair work for flood damage		loss due to repair work for flood damage	
	E C	NPW	E C	NPW	E C	NPW	E C	NPW
Sasoma	7.72	83.53	12.70	137.4	7.06	76.39	14.13	152.89
Zunker	15.468	167.36	25.42	274.8	14.13	152.74	28.26	305.49
Umbung	30.94	334.46	50.85	549.6	28.26	305.5	56.52	610.98
Pahalgam	894	9673	146.97	1590.2	81.65	883.45	163.30	1766.90
Jhanjavati	618.4	6691.0	169.50	1833.9	285.53	3089.40	565.00	6113.27

Table 10. Life Cycle Cost of raised gravity weir, trench weir and bush and boulder weir for Sasoma Project

Item	Raised Gravity		Trench Weir		Bush and Bolder	
	E C	P W	E C	P W	E C	P W
Total initial cost	120	120	118	118	33	33
a) Expenditure after 5 years Amt x pwf = (pwf=.5674)					18.48	10.485
b) Expenditure after 10 years Amt x pwf = (pwf=0.3220)	29	9.388	42	13.524	72.6	23.37
c) Expenditure after 15 years Amt x pwf = (pwf=0.1827)					46.2	8.440
d) Salvage after 20 years Amt x pwf = (pwf=.1037)						
NPW of losses				220.939		76.38
Annual cost (O&M) Amt x upwfUpwf =10.047.	3.65	36.67	3.9	39.18	10.2	102.47
Life Cycle Cost		166.05		391.643		254.16

Table 11. Life Cycle Cost of Mathu bund, Indian Rubber Dam and Imported Rubber Dam for Sasoma Project

Item	*Mathu* Bund		Indian Rubber Dam		Imported Rubber Dam	
	E C	P W	E C	P W	E C	P W
Total initial cost	28	28	30	30	115	115
a) Expenditure after 5 years Amt x pwf = (pwf = .5674)	44.8	25.42				
b) Expenditure after 10 years Amt x pwf = (pwf = 0.3220)	61.6	19.835	18	05.796	69	22.22
c) Expenditure after 15 years Amt x pwf = (pwf = 0.1827)	78.4	14.323				
d) Salvage after 20 years Amt x pwf = (pwf = .1037)			9	00.9333	34.5	3.57
NPW of losses		152.88				
Annual cost (O&M) Amt x upwf Upwf = 10.047.	10	100.47	1.5	15.07	2.05	20.59
Life Cycle Cost		340.9		49.97		154.2367

Table 12. Life Cycle Cost (INRx10^5) of different types of weirs for different discharge values

Project	Type of Weir Discharge (Cumecs	Raised Gravity	Trench Weir	Bush and Bolder	*Mathu* Bund	Indian Rubber Dam	Imported Rubber Dam
Sasoma	2.5	166.1	391.6	254.2	340.9	50.0	154.2
Zunkur	5	607.9	1405.3	1019.2	1585.1	174.4	549.0
Umbulung	10	617.3	1689.1	1076.4	1641.5	155.4	494.9
Pahalgam	28.9	281.3	1152.2	1155.9	2085.5	84.6	262.3
Jhanjhavati	100	771.4	9293.4	3884.3	7002.3	230.0	734.2

Table 13. Life Cycle Cost (INRx10^5) per unit length of different types of weirs for different discharge values

Project	Type of Weir Discharge (Cumecs)	Raised Gravity	Trench Weir	Bush and Bolder	*Mathu* Bund	Indian Rubber Dam	Imported Rubber Dam
Sasoma	2.5	9.23	21.76	14.12	18.94	2.78	8.57
Zunkur	5	18.42	42.58	30.88	48.03	5.28	16.64
Umbulung	10	17.64	48.26	30.75	46.90	4.44	14.14
Pahalgam	28.9	9.22	37.78	37.90	68.38	2.77	8.60
Jhanjhavati	100	12.86	154.89	64.74	116.71	3.83	12.24

using Present Worth Method of different types of weir for water withdrawal value of 2.5 cumecsin case of Sasoma Hydroproject is given in Tables 10 and 11 (PW = present worth and EC = estimated cost).

6. Results

The procedure shown above for working out the life cycle cost was repeated for other four projects. Present Net Worth (PNW) of the projects for different discharge values for different projects are given in Tables 12 and 13.

7. Conclusion

- The experience of inflatable dams in India is very limited as there are only three installations so far for irrigation or municipal use. Use of inflatable weir for diverting water in hydropower projects has not been experienced in India till date.
- Life cycle cost of imported rubber dam as well as Indian rubber dam is found to be less than all the conventional types of weirs. Average Life Cycle Cost of imported rubber dam is about three times more than Indian rubber dam.
- With the comparative analysis, it is found that average Life Cycle Cost of raised gravity weir, bush and boulder, *mathu bund* and trench weir is 2, 3, 5 and 6 times respectively more than imported rubber dam.
- Life Cycle Cost of Indian rubber dam is found out very low but more study should be carried out before it is used for hydropower projects in India as it has been designed primarily for irrigation purposes in flatter areas not having boulder and trash movement.
- Use of rubber dams for Small Hydropower projects should be encouraged because of its shorter construction time, structural simplicity, flexibility, proven reliability, ease of operation and low Life Cycle Cost.

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