Introduction of Flap Gates for Anicuts in Wet Zone

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Abstract— Water diversion mechanisms are commonly used in the irrigation systems and this concept is older than tank (reservoir) systems in Sri Lanka. At present, for water diversions in the wet zone anicuts are constructed by using lifting type gates. Anicuts are used to maintain required water level in the upstream by releasing only the excess water to downstream. In the lifting gate, water is allowed to flow from the bottom and this causes high erosion in the canal. The thrust force due to water pressure on the lifting gate makes it difficult to operate the system and then controlling the system is a complex task. This paper describes the construction and operation of newly introduced flap gates and issues related to lifting gate which are presently used for diversion process. In this analysis, conceptual design of a flap gate with compressive arc type wall plate is proposed to minimize use of construction materials. In the proposed system, height of the anicut could be changed from the top and then the water level in the upstream is not varied much when compared with lifting gates for varying flows in the cannel. According to the practical experiences from implemented proposed systems, controlling of the system is much easier compared to the conventional system.

Keywords—Anicuts, Flap gate, lifting gate, water diversion system

I. Introduction

The south - west wet zone of Sri Lanka which basically covers the districts Kegalle, Gampaha, Colombo, Kalutara, Ratnapura, Galle and Matara has many perennial rivers. Their flows account for a mean of 49 % of the total mean annual yield of all the rivers of Sri Lanka. But the wet zone catchments total only up to about 19 % of all catchments area of Sri Lanka. This gives an idea of the degree of wetness of the catchments in this zone. This wet zone generally encompasses the south – western plains and the mountainous quarter and covers an area of about 12,205 km^2. Annual rainfall is somewhat evenly distributed during the year; with the maximum rainfall is recovered during the south-west monsoon in the months of May and June. The agricultural development in this zone is mainly by rain fed cultivation together with few anicut schemes diverting the stream flow, without any irrigation storage reservoirs[1]. The cultivation in the low lands has generally been paddy with mostly double cropping.

In rainy season, the streams which contribute to the perennial rivers flow with high water depths and this reduces the floods in the area. In dry season, flow will be with a low water depth. But a substantial flow takes place throughout the year.

In the wet zone anicut is the most important feature related to soil-water and agriculture. They can be categorized into different groups after considering the topology of the area where this particular structure is located. Approximately there are about 12,950 anicuts in this zone and most of them are virtually in abandoned state [2]. If all of these could be refurbished, about 250,000 acres of paddy land could be cultivated easily. Also, flooding in the related areas could be reduced with less soil erosion..

II. The Subsurface Irrigation System

Sri Lanka traditionally has been an agricultural country and ancient Sri Lankans have demonstrated superior skills in irrigation and water resources development[3]. The indigenous system was to raise the water level by constructing a stick dam across the water way and thereby maintaining a perched water table within the wet zone area of paddy lands adjacent to the water way. This sub surface irrigation system seemed quite efficient and appropriate at that time. The indigenous system was not only an irrigation system; instead it was a total soil-water- eco system[4]. The aim of this system was to supply water for the whole eco system not only for the root zone of a particular crop. Therefore canals need only to carry excess water from a particular area. Canals served not only as a water conveying mechanism but also as storage. In ancient anicuts,

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excess water flows from the top. Anicuts were used to maintain required water level in the upstream by releasing only the excess water to downstream[5]. Height of the anicut could be changed from the top. Therefore, the controlling of the system was very easy.

Fig. 1. Picture of Danduwana flap gate

However from the beginning of the colonial era and afterwards in most places these streams were deepened to minimize the floods in the vicinity and concrete structures with lifting type gates were introduced to raise the water in the dry season. Severe problems occurred when these concrete structures were introduced for shallow water ways in alluvial plains. In modern irrigation systems which aim at providing water only for root area of crops, the anicuts were constructed using lifting type gates. The speed of water flows from the opening at the bottom of these gates is very high and stream bed erosion keeps on deepening the stream more and more which worsens the water availabilities in the downstream. The logs and debris coming with the flood water could block the stream at the structure leading to floods in the whole area and it is very difficult to remove these blocks even after the rains are over. Frequently with high rain falls, the whole anicut structure gets flushed away due to high water forces on it. The blockage related with lifting gear makes it very difficult to control the water level in the upstream side where water was taken to paddy fields. Not only the opening height of gates but the inflow also plays a vital role in determining the water depth in the upstream. Therefore to maintain a required depth of water in the upstream, the opening height of gates has to be changed with the inflow, if not when the opening is too low the upstream side will be flooded and if the opening is too high water supply for paddy fields will be restricted due to lowering of water level in the upstream side. The high friction between these sliding type doors and guides makes it extremely difficult to operate these gates even with a screw mechanism. The long term experience in the above circumstances felt the necessity of a flap gate which could be identified as the modern version of ancient stick dam for village diversion structures. In flap gates if the hinges are at the bottom of channel, at fully open position, the gate is in horizontal position and induces no restriction for channel flow. This feature is very important in flooding. Figure 1 shows a flap gate (5.6 m width, 1.8 m high) constructed by National Engineering Research & Development Centre of Sri Lanka (NERDC) at Danduwana canal in Galle district.

III. CONTROL OF WATER DEPTH IN UPSTREAM

The main purpose of the anicut is to maintain upstream water level for subsurface irrigation. Water flow rate can be derived as a function of upstream water level of the anicut for each type of water gate. The upstream water level of the lifting and flap gate is illustrated in Figure 2 and Figure 3 respectively.

For the lifting gate (see Figure 2), water flow rate Q, is expressed by h and b. Where; h=lifting height of the gate and b=6m; breadth of the gate.

$$Q=b(2gh)^{1/2}[h^{3/2}-(h-H)^{3/2}] \qquad (1)$$

For the flap gate (see Figure 3), water flow rate Q, is expressed by h and b. Where; h=height of the water flow and b=10m; breadth of the gate

$$Q=(2/3)b(2g)^{1/2}(h^{3/2}) \qquad (2)$$

The graph of upstream water level (h) Vs Q is plotted in the Figure 4, for H=0.25, 0.5, 0.75 and [$0<h<2$ m]

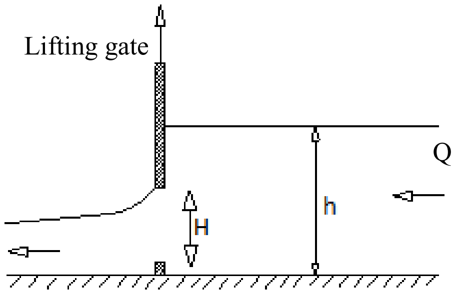

Fig. 2. Lifting type gate

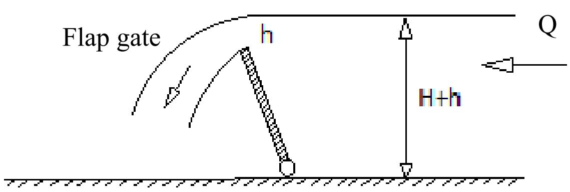

Fig. 3. Newly introduced flap gate

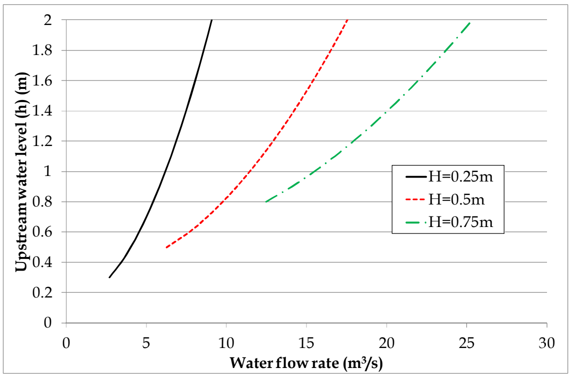

Fig. 4. Upstream water level (h) Vs Q for the lift gate

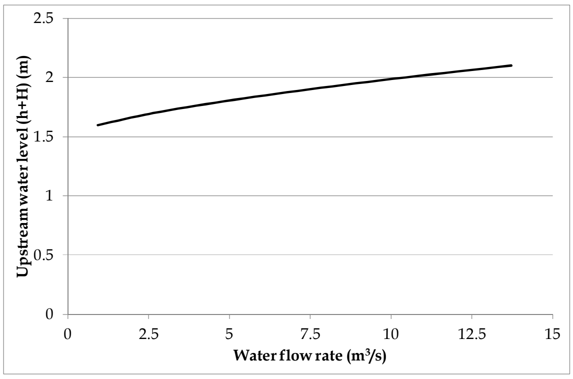

Fig. 5. Upstream water level (h+H) Vs Q for the flap gate

The graph of upstream water level (h+H) Vs Q is plotted in the Figure 5, for [0 < h < 0.6 m].

According to the Figure 4 and Figure 5, upstream water level of flap gate is not much varied with the water flow rate when comparing with the lift gate. Therefore by using flap gates, water flow for downstream supply can be critically controlled while maintaining upstream water level.

IV. PROPOSED FLAP GATE WITH COMPRESSIVE WALL PLATE

This study is based on a flap gate of size 10 m x 2 m with a compressive wall plate, which was designed and fabricated at NERDC of Sri Lanka with the request of the Department of Agrarian Development. This flap gate was installed in the site at Kosgama by replacing previously installed lift gate, which was failed in operation. A picture of the flap gate installed at Koasgama is shown in Figure 6. The architecture of proposed flap gate was simple and one gate shutter with hinge facility at bottom was introduced. A schematic diagram of the proposed flap gate is shown in Figure 7. Length of the gate shutter was equal to the width of the stream and the gate was made out of heavily galvanized steel frame and the skin plate attached by nuts & bolts. The gate was mechanically controlled by iron ropes, pulleys, and a chain bullock lifting mechanism is shown in Figure 8 and the gate could be kept at any position between vertical (fully closed) and horizontal (fully opened). According to Figure 9 the hydrostatic forces acting on the gate (plates) are transmitted to the horizontal GI pipe (diameter 100 mm) at the bottom and to the truss situated upwards from the bottom horizontal line of the gate. This truss is supported by two trusses at each end, which also support the pulleys required to guide and hold the cables which are required to lift the gate.

Fig. 6. A picture of the flap gate installed at Kosgama

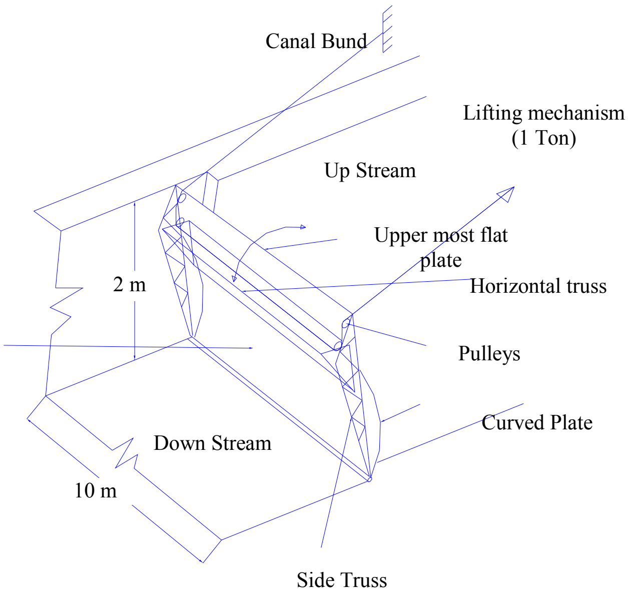

Fig. 7. Schematic of proposed flap gate

The bottom part (sheets) of the gate is designed in such a way that only compressive stresses are induced within the plates. This eliminates the requirement for additional supports in the vertical direction to withstand the non uniform force in the tangential direction to the hydrostatic forces which is explained by considering a small 'δl' element of the curved section of gate as shown in Figure 9.

The elevation of flap gate is shown in Figure 10. The shape of the OA part is determined in such a way that only compressive stresses are induced in the direction of 'δl'. Forces on 'δl' is considered (An element with unit width and thickness t)[6].

Fig. 8. Picture of lifting mechanism at Kosgama

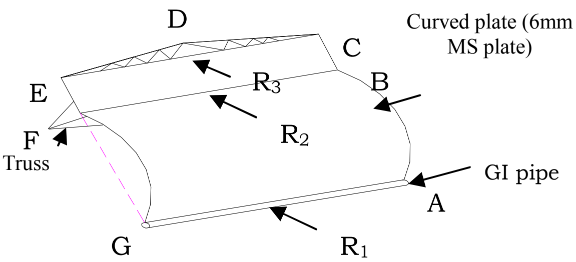

Fig. 9. Forces Acting on Individual Elements

t = thickness of element 'δl'

σ_c =Compressive Stress (This is maintained as a constant value along the curvature of the gate)

R = radius of curvature of element 'δl'

Then pressure at a height 'h' from bottom= (H-h) ρg

$$\delta\theta\, t\, \sigma_c=(H-h)\rho g R\, \delta\theta \tag{3}$$

$$R= t\, \sigma_c/(H-h)\, \rho g \tag{4}$$

σ_c and t are constants

$$1/R = [(d^2y)/(dx^2)] /[1+(dy/dx)^2]^{3/2} \tag{5}$$

Total Force acting on AB curved plate $=10 \int_{0.67}^{2} x\rho g\, dx$

$= 17.7555$ ton

Total Force acting on BC plate

$= 10\int_{0}^{0.67} x\rho g\, dx$

$= 2.2445$ ton

Total force acting on curved plate is transferred to GI-pipe and truss FB. Force acting on BC plate is transferred to truss FB and truss CDE.

Force acting on GI pipe, R_1

R_1 = 17.7555 - 17.7555/3 ton

= 11.837 ton

Force acting on truss FB, R_2

R_2 = 17.7555/3 + 2.2445×(2/3)

= 7.415 ton

Force acting on truss FB, R_3

R_3 = 2.2445/3

= 0.748 ton

Force R2 is transferred to EGH and CIA trusses as shown in Figure 11.

The shape of the curved surface which is given by radius of curvature (R) can be analysed by the equating equation (4) and (5).

$$(H-x)\, \rho g/ t\, \sigma_c= - [(d^2y)/(dx^2)]/[1+(dy/dx)^2]^{3/2} \tag{6}$$

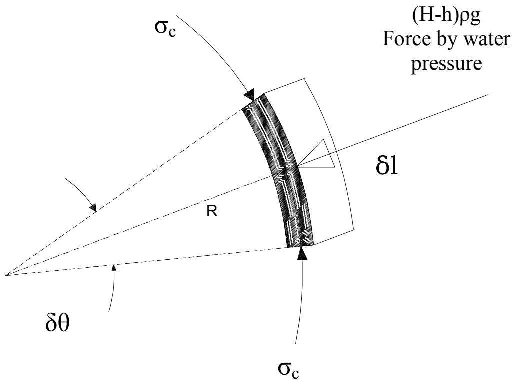

Fig. 10. Forces Acting On an Element of δl in Curved Section of Flap Gate

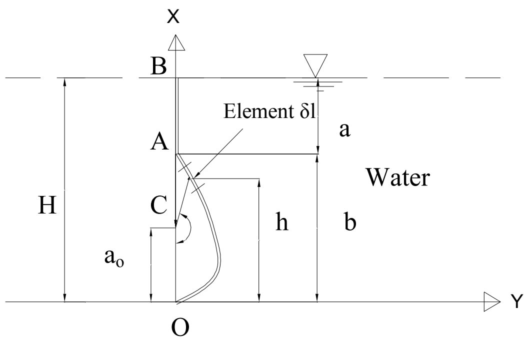

Fig. 11. The elevation of flap gate

Equation (6) was solved by using a MATLAB/SIMULINK model and the developed model and results are given in the Appendix (see Figure 13). Following values are used for the constants in the model; H= 2 m, ρ =1000kg/m^3, g = 9.81m/s^2 σ_c=98100000 N/m^2 (Applying safety factor of 50% for Mild Steel and assuming tensile strength of 196.2 MPa)
t = 0.006 m
Upper limit for the equation [x=1.3 y=0]
Lower limit for the equation dy/dx=0.02161

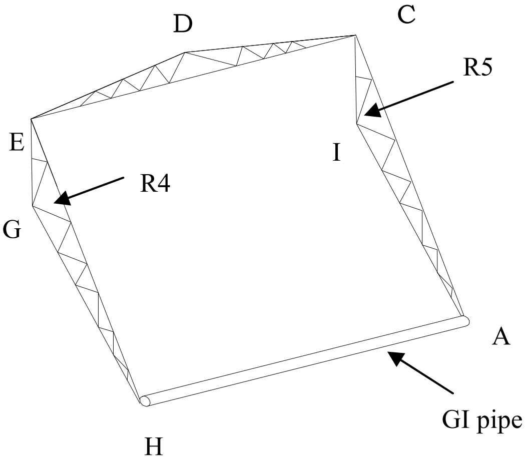

Fig. 12. Side View of the Gate

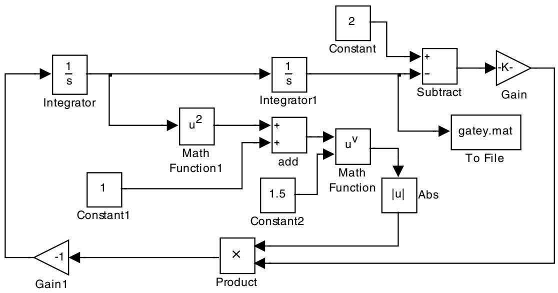

Fig. 13. MATLAB/SIMULINK model

V. DISCUSSION

In this design, it was possible to use 6mm thick plate for the curved section in the bottom only with minimum vertical supports just to retain the structure. No bending moments are induced in the bottom curved section (curved plates) part. This curved surface merely transmitted the forces on it to bottom GI-pipe and to the truss at the middle.

This study intends to introduce flap gates for anicuts type water diversions. In sliding type lift gates, high friction between doors and guides makes it extremely difficult to operate even with screw mechanism. In Flap gates, water pressure is not applied to generate any friction force at the operation of the gate and then flap gates can be simply operated by a hand wrench. By practical experiences in Kosgama, the flap gate can be easily operated and control water flow with compared to the previous installed lift gate in the same place.
According to the characteristics of the catchment related to the channel at Kosgama flap gate site, flow rate in the channel is highly sensitive to rain. A rain of 10-20 mm for few hours would easily flood an area with houses and roads, if sudden opening of the gate is impossible. Unlike with lifting type gates the introduced flap gate enables this opening very easy

VI. CONCLUSIONS

Anicuts with flap gate mechanism can be identified as an eco-friendly water diversion system for subsurface irrigation. This mitigates soil erosion due smooth water flow. In this research, curved shape compressive wall plate was introduced to minimize material usage. A 6 mm thick plate was used in this research for the curved section at the bottom with minimum vertical supports to retain the structure. The flap gate provides the facility to be operated even by a hand wrench, as it is not subjected to the friction forces imposed by water pressure. This feature is important for flood control, which would otherwise damage people and property if immediate opening of the gate is impossible.

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